Impacts and Potential Impacts of Spotted Knapweed (*Centaurea maculosa*) on Forest and Range Lands in Western Montana

by

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Final Report
June, 1988

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Three graduate research assistants worked on certain phases of the project and reported the results in M.S. theses: Jeffrey L. Carpenter (study reported in Chapter II), Gloria B. Mooers (study reported in Chapter III) and Darlene Anne Lavelle (study reported in Chapter IV). Their long hours of work devoted to completion of this research is greatly appreciated.

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We were fortunate to have the able assistance of Crystal Moen, Russ Offerdahl, Rebecca Greenwood, Q Carpenter and Peter Carroll, students at the University of Montana. Their persistence through heat and cold, often-tedious data collection in field plots, and imposed deadlines provided the quality of help required to get the work accomplished.

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SUMMARY

This study was funded from July 1, 1984 to September 30, 1987 through the Department of State Lands with NAPIAP funds (FS-410 appropriation number) administered by Region I of the Forest Service. The major objective of the study was to determine the impacts and potential impacts of spotted knapweed on forest and range lands in western Montana. Specific objectives were:

1. To assess the responses of vegetation to control of spotted knapweed by use of selected herbicides and fire.
2. To assess the possible response of deer and elk to various spotted knapweed control treatments on their winter range.
3. To determine the importance of spotted knapweed on various forest and grassland habitat types.
4. To determine the importance of soil/vegetation disturbance in establishment and spread of spotted knapweed.
5. To assess changes in deer and elk winter range quality as influenced by increases in spotted knapweed.
6. To assess the impact of spotted knapweed on establishment of tree seedlings on harvested areas.

A field study was initiated to compare the effects of four herbicides for spotted knapweed control. Picloram, clopyralid, picloram + clopyralid, and metsulfuron methyl were sprayed on three spotted knapweed infested range sites. The objectives

were: 1) to determine which herbicide(s) provide the best control of spotted knapweed, 2) to determine whether burning prior to spraying would increase herbicide effectiveness, 3) to determine grass standing crop response following treatment, and 4) to compare herbicide effects on non target forb species.

Herbicides were applied during the spring of 1985. Standing crop was measured by clipping 0.5 m^2 sample plots three months and 15 months after spraying. Density measurements were used to compare treatment effects on non target forb species.

The most effective herbicide for spotted knapweed control was picloram, followed by picloram + clopyralid, clopyralid, and metsulfuron methyl. Picloram, picloram + clopyralid, and clopyralid provided 100% initial control. After 15 months, 0.42 kg/ha of picloram continued to prevent spotted knapweed growth. All other treatments were reinfested to some degree, with clopyralid having the least residual effectiveness. Metsulfuron methyl initially suppressed knapweed growth, but did not kill this species. Burning had no apparent influence on herbicide effectiveness.

On treatments that initially controlled knapweed, total grass standing crop increased by up to 375%, 15 months after treatment. Kentucky bluegrass, Canada bluegrass, and prairie junegrass increased more readily than species such as rough fescue, Idaho fescue, and bluebunch wheatgrass; however, all grasses were observed to increase in size and vigor following knapweed control.

Clopyralid was the most selective herbicide for the forb

species tested. Picloram + clopyralid was of intermediate selectivity. Picloram and metsulfuron methyl which were least selective, causing considerable damage to several non target forb species.

Another study was conducted to identify the environmental factors that most affect spotted knapweed success in Western Montana. Environmental data describing sites where spotted knapweed currently occurs were collected throughout western Montana in all major habitat types and in every area west of the Continental Divide where spotted knapweed is currently a problem. Over all habitat types spotted knapweed success was correlated with degree of disturbance and with moisture-stressed environments. However, the variable that explained the most variation in average distance between knapweed plants changed as the site conditions changed. In habitat types wetter than the Douglas-fir (Pseudotsuga menziesii) group, disturbance intensity influenced spotted knapweed success the most, while soil texture and topographic position were also important. In the grass and shrub habitat types, aspect was the most important predictive variable, followed by disturbance intensity. In the intermediate habitat types no single variable was consistently more important in influencing knapweed success.

Use and preference of spotted knapweed by Rocky Mountain elk (Cervus elaphus) and mule deer (Odocoileus hemionus) were investigated on the Threemile and Calf Creek game ranges in western Montana. Use was assessed from pellet analyses and preference data were evaluated from use and availability

measurements obtained on feeding sites. Forage value of knapweed on open and forested sites was determined by analyzing percent crude protein, fiber, and lignin content of the dried flower tops.

Deer consumed small amounts of knapweed flowers throughout the study period on both ranges while elk consumed small amounts only during winter. On a very few feeding sites, knapweed was preferred by deer and elk over other plant species. Knapweed consumption seemed to be related to its high availability.

Crude protein content of knapweed flowers was similar for open and forested sites; mean content was 6.6%. On forested sites, fiber and lignin contents were significantly ($P \leq 0.05$) higher than on open sites, approximately 2% and 4%, respectively. High crude protein and low lignin values associated with these flower tops indicate that their digestible energy will be high. However, since use of knapweed is limited to the flower tops and upper stems, the amount of useable forage is drastically reduced.

Areas dominated by spotted knapweed were not utilized as major feeding areas by deer and elk. Knapweed infestations seemed more detrimental to elk than to deer because the elk diet consisted mainly of grasses (which knapweed has replaced) compared to the evergreen shrub and tree diet of deer. Management of elk and deer winter ranges with high knapweed densities may require herbicide treatment of knapweed, replanting with desirable and nutritious rhizomatous grasses, and grazing by cattle to prevent the build-up of grass litter.

All treatments using large amounts of organic matter

increased disease problems, probably by increasing the energy source to soil microorganisms. Treatments using the top-growth of knapweed plants did not have an additional phytotoxic effect on germination or growth of lodgepole pine (Pinus contorta), Douglas-fir (Pseudotsuga menziesii) or western larch (Larix occidentalis), or to photosynthesis or growth of ponderosa pine (Pinus ponderosa) seedlings. However, phytotoxicity to germination and survival of western larch, lodgepole pine, and ponderosa pine was observed when only leaf material of knapweed was applied. The phytotoxicity observed was at rates believed to be higher than those found in nature.

Phytotoxic effects of knapweed leaves to germination and survival were more evident for ponderosa pine when the growth medium was sand than when the growth medium was a vermiculite mix. The more evident phytotoxicity caused by knapweed leaves applied to the sand medium was related to two factors: (1) Within treatment variation was much greater in seedlings grown in a vermiculite soil mix because of "damping off", and (2) Toxicity was probably decreased in the vermiculite mix because of absorption of the toxic compound to soil particles and greater degradation of cnicin.

Ponderosa pine survival was increased where knapweed was controlled. Increased survival was probably related to a decrease in competition for water and was not believed to be related to allelopathy since knapweed had been growing on the site and knapweed litter was still present in the soil.

The large amount of knapweed leaves necessary to cause a

significant decrease in germination and survival of ponderosa pine, western larch, and lodgepole pine suggests that there are other factors leading to the success of knapweed on clearcuts and grassland sites. From our research and other studies we believe that knapweed's success is related to its ability to compete for resources in short supply. Once knapweed is controlled there is a rapid increase in growth of existing plants because of additional resources. The increase in growth is about equal to the amount of knapweed controlled.

Knapweed begins growth very early in the spring which increases its ability to compete for resources. When knapweed was introduced into North America natural enemies such as herbivores and diseases were left behind in Europe. It is very likely that the ability of knapweed to compete for water and nutrients is greatly increased because of its limited utilization by insects, mammals and possibly from soil fauna when compared to the surrounding vegetation. Therefore, it is our belief that the introduction of knapweed has changed the competitive balance of many sites in western Montana. This competitive imbalance has shifted these sites to knapweed domination.

RECOMMENDATIONS FOR FUTURE RESEARCH

Following completion of this research project, it has been determined that the following research is needed to better understand the ecology and possible control of spotted knapweed:

1. Some effective control methods were identified in our research. However, the question arises about possibilities of reducing or preventing reinfestation of spotted knapweed on a treated site. Treatments might include use of periodic burning and seeding to control knapweed seedling establishment. The species selected for seeding, i.e. sod-former vs. bunchgrass, may be important in preventing reinvasion.

2. Further investigations should examine the density of knapweed infestations over time to determine if infestations might eventually decline, perhaps in response to phytotoxic chemicals produced by knapweed itself, or whether sites suitable for knapweed continue to support dense stands over an extended period of time.

3. During the course of our investigations on use of herbicides, it became obvious that a number of the forb species were susceptible to these chemicals. One concern among land managers and conservationists is to maintain plant species diversity on rangelands. There is a need to investigate plant species diversity (especially forbs) on a) sites infested with spotted knapweed, b) sites where various methods (herbicides, fire, etc.) of controlling spotted knapweed have been applied for an extended period of time (1 to several years), and c) sites

where natural plant communities have no spotted knapweed, nor have fire and herbicides been applied.

4. More information is needed concerning the most cost-effective rate to spray, best time to spray, and herbicide effects on forbs other than those included in this study. In addition, there may be other herbicides that will effectively control knapweed, but with less cost or more selectivity.

5. There is a need to study the current location and acreage of spotted knapweed in Montana, along with the potential for spread into unoccupied habitats. The possibility of using LANDSAT and SPOT data, coupled with a Geographic Information System (GIS) to accurately supply this information, needs to be explored.

ACTUAL COSTS

NAPIAP funds (FS-410 appropriation number) - - - - - $118,750

PLANS FOR PUBLICATION

This research project contains several studies, each of which will be developed into one or papers for publication. Our plans are to develop papers to be submitted to appropriate journals. The journals which we have in mind include the Journal of Range Management, Weed Science, and Forest Science. Another

source for publications is the Montana Forest and Conservation Experiment Station. Three M.S. theses have already been developed from portions of the research. These include:

Carpenter, Jeffrey L. 1986. Responses of three plant communities to herbicide spraying and burning of spotted knapweed (Centaurea maculosa) in western Montana. M.S. Thesis, Univ. of Montana, Missoula. 110 pp.

Mooers, Gloria B. 1986. Relationship of critical environmental factors to the success of spotted knapweed (Centaurea maculosa) in western Montana. M. S. Thesis, Univ. of Montana, Missoula. 30 pp.

Lavelle, Darlene A. 1986. Use and preference of spotted knapweed (Centaurea maculosa) by elk (Cervus elaphus) and mule deer (Odocoileus hemionus) on two winter ranges in western Montana. M. S. Thesis, Univ. of Montana, Missoula. 72 pp.

POTENTIAL PATENTS

No patents will be forthcoming from this research.

CHAPTER I

INTRODUCTION

A weed by definition is "any undesired, uncultivated plant that crowds out desired ones" (Webster 1972). Extensive weed stands on range and forest lands are usually the result of past disturbances such as overgrazing by livestock, drought, cultivation of introduced forage crops, logging operations and road construction. Low elevation sites are more accessible, and therefore more susceptible to man-caused disturbances and the spread of weedy plants than high elevation sites. Displacement of native forage by weeds is now an aesthetic and economic problem. One weed in particular, spotted knapweed (Centaurea maculosa), has invaded many disturbed sites in western Montana.

Spotted knapweed is classified as a noxious weed in many states. The plant is native to Europe and western Asia. Knapweed was probably introduced to North America as a contaminant of hay and/or alfalfa seeds. During the past century, knapweed, along with several other noxious weeds, has invaded forest and grazing lands throughout Montana.

Spotted knapweed was first collected in British Columbia, Canada, in 1893 (Watson and Renney 1974); Montana State University records show its collection in Montana first occurred in Ravalli County, Montana, in the mid-1920s. By 1974 it occupied nearly 202,429 ha in Missoula County alone. Spotted knapweed now occupies 647,773 ha in the state and is present in

every county (French and Lacey 1983, Chicoine 1984). Originally an intruder only of disturbed rangelands (Morris and Bedunah 1984), spotted knapweed now exists in nearly every habitat type west of the Continental Divide; it ranges from the driest bitterbrush/ bluebunch wheatgrass (Purshia tridentata/Agropyron spicatum) zone to the lush western hemlock/beadlily (Tsuga heterophylla/ Clintonia uniflora) forest.

After establishing in an area, spotted knapweed density often increases. Simultaneous production of desirable forage decreases, sometimes by as much as 90% (Baker et al. 1979, Harris and Cranston 1979). This causes serious financial losses to ranchers, and it reduces the capacities of big game ranges to produce winter forage (Spoon et al. 1983). Even western Montana's timber-producing potential may be threatened because spotted knapweed competes with conifer seedlings for water and nutrients (Spoon et al. 1983). Also, spotted knapweed has an allelopathic toxin that has inhibited germination of larch (Larix occidentalis) seeds and reduced the growth of larch and lodgepole pine (Pinus contorta) seedlings in laboratory tests (Kelsey and Locken, in press).

Spotted knapweed has aggressively invaded extensive areas of Montana rangelands. As knapweed increases, production of more desirable but less competitive grasses and forbs significantly decreases (Harris and Cranston, 1979). Problems resulting from spotted knapweed invasion include economic losses due to reduced livestock production, as well as environmental damage, e.g. reduced vigor of native plant populations, displacement of elk

from normal winter ranges, and less plant diversity on infested sites.

Attempts to reduce the spread of spotted knapweed have been largely unsuccessful. Many control methods have been studied, but most have been either ineffective, or unacceptable for widespread use. One method of control that has shown promise is the use of selective herbicides. Of the herbicides tested, picloram has given the best long-term spotted knapweed control (Renney and Hughes, 1969; Chicoine, 1984).

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CHAPTER II

RESPONSES OF THREE PLANT COMMUNITIES TO HERBICIDE SPRAYING AND BURNING OF SPOTTED KNAPWEED IN WESTERN MONTANA

Introduction

Spotted knapweed (Centaurea maculosa) has aggressively invaded extensive areas of Montana rangelands. As knapweed increases, production of more desirable but less competitive grasses and forbs significantly decreases (Harris and Cranston, 1979). Problems resulting from spotted knapweed invasion include economic losses due to reduced livestock production, as well as environmental damage, e.g. reduced vigor of native plant populations, displacement of elk from normal winter ranges, and less plant diversity on infested sites.

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The primary objective of this study was to assess changes in three plant communities after spraying herbicides for spotted knapweed control. Specific objectives were: 1) to determine which herbicides(s) provide the best control of spotted knapweed, 2) to determine whether burning prior to spraying would increase herbicide effectiveness, 3) to determine grass standing crop response following treatment, and 4) to compare herbicide effects on non-target forb species.

The four herbicides used were: picloram (4-amino-3,5,6-trichloropicolinic acid), clopyralid (3,6-dichloropicolinic acid), picloram + clopyralid, and metsulfuron methyl (methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoate). Some treatments consisted of burning prior to spraying, to determine if burning altered herbicide effectiveness. Standing crop of spotted knapweed and major grasses, and changes in forb composition, were measured to determine the overall changes in the plant communities.

Literature Review

Spotted knapweed is native to eastern Europe. The species was introduced to North America as a contaminant in European alfalfa seed, and was first noted near Victoria, British Columbia, during the late 1800's (Maddox, 1982). Spotted knapweed spread from British Columbia, reaching western Montana by the mid 1920's (Story, 1984). Knapweed now infests approximately 810,000 ha in Montana and about 32,000 ha in both Idaho and Washington (Maddox, 1979). Spotted knapweed spread is

considered to be the worst weed problem on western Montana rangeland (French and Lacey, 1983), with infestations occurring in every Montana county (Bucher, 1984).

Biology

Spotted knapweed is a short-lived perennial plant with two growth forms. During its first year the plant develops a rosette, from which flower stems emerge during the second and subsequent years. The flower heads bear numerous seeds, which provide the primary means of reproduction. Seeds normally fall very close to the parent plant (Renney and Hughes, 1969); however, they are easily transported from existing stands via animals, vehicles, hay, etc., allowing rapid formation and spread of new infestations.

Knapweed seeds will germinate under a wide range of conditions. Spears et al. (1980) studied the effects of seeding depth, initial soil moisture, and canopy cover on spotted knapweed emergence. Seeds on the surface germinated most readily. At least 55% initial soil moisture was required for germination, with 70% resulting in the highest germination rates. Canopy cover had no recognized effect on seed germination.

The season of germination influences spotted knapweed's ability to produce flowers. Schirman (1981) found that most plants germinating in March and April produced flowers during their second year, while plants germinating in June, July, or later, did not flower until their third year of growth.

Several characteristics enhance spotted knapweeds competitive advantage over most native plant species. First, as

an introduced species, knapweed has few natural enemies in North America. In addition, the environment of the northwestern United States and southwestern Canada is similar to regions in Europe where knapweed is naturally most aggressive (Harris and Cranston, 1979). This combination makes spotted knapweed extremely competitive for nutrients (Belles et al. 1980) and soil moisture.

Other advantages stem from knapweed's versatility. The plant can produce seed with below normal rainfall, and then invade areas where other vegetation is weakened by drought (Baker et al. 1979). Similarly, spotted knapweed can grow during the early spring and late fall, becoming established and using nutrients while most plants remain dormant (Baker et al. 1979).

Most grazing animals selectively avoid spotted knapweed. Locken (1985) concluded that cnicin, a bitter tasting chemical in knapweed leaves, probably acts to deter grazing. Cnicin was originally thought to give spotted knapweed allelopathic activity against other plants (Fletcher and Renney, 1963), but recent evidence indicates that spotted knapweed has little if any allelopathic effect (Locken, 1985).

A final advantage of spotted knapweed is its enormous seed production. Estimates of seed production range from an average of 349 (Watson and Renney, 1974) to about 1000 (Schirman, 1981; Story, 1976) seeds per flowering plant per year. Some seeds can remain viable in the soil for at least 5 to 6 years (Chicoine, 1984), and are thus available to reinfest a site after growing plants are removed.

Losses Caused by Knapweed Invasion

Reduced forage production is the primary problem on knapweed-infested rangeland. Harris and Cranston (1979) found that forage production declined to as little as 12% of normal in bluebunch wheatgrass/rough fescue (*Elymus spicatus*/*Festuca scabrella*) grasslands in British Columbia. Bucher (1984) estimated that average forage production on infested grasslands is reduced more than 60 percent. This forage loss could cost Montana's cattle and sheep industry more than 150 million dollars annually (Bucher, 1984).

The cost of spotted knapweed aggression extends well beyond monetary losses suffered by ranchers. Elk winter ranges are among the most susceptible areas, and many have been extensively invaded. Spoon et al. (1983) estimated that elk populations on the Lolo National Forest could decline by up to 220 animals per year by 1998, and that most of this decline would be directly attributable to forage losses caused by spotted knapweed invasion.

Control

Attempts to reduce the spread of spotted knapweed have met with little success. Burning is not effective because seeds in the soil are protected and can quickly reinfest the site (Renney and Hughes, 1969). Mowing is also ineffective (Baker et al. 1979) because flowers develop from buds near the ground after the top of the plant is removed.

Several biological control agents have been tested for knapweed control. Cox (1983) found that high intensity grazing

by sheep could essentially eliminate spotted knapweed seed production. A disadvantage is that several years of extremely heavy grazing to control knapweed would probably result in considerable damage to desirable forage species, and would provide a highly disturbed site that is susceptible to knapweed reinvasion.

A native fungus, Sclerotinia sclerotiorum, has shown potential as a biological control agent. Several isolates of this species were applied to spotted knapweed, and preliminary results have shown that some of the isolates increase spotted knapweed mortality (Bedunah, 1986).

Another option for biological control is to obtain natural insect enemies from Europe for release in North America. Two seedhead gall flies, Urophora affinis and U. quadrifasciata, are widely established on spotted knapweed in Montana (Story, 1984). The larvae of these flies form galls in knapweed flower heads, thereby diverting energy from seed production (Story and Nowierski, 1984). The presence of galls has resulted in lowered seed production (Harris, 1980), but not enough to slow knapweeds spread (Maddox, 1982). A seed eating moth (Metzneria paucipunctella) and a root mining moth (Agapeta zoegana) have been released more recently (Story and Nowierski, 1984). It is hoped that the combined effects of these four insects, along with others that may be released, will eventually reduce knapweed's competitive advantage.

Herbicides have been used with some success for knapweed control. Picloram has proven most effective, providing excellent

initial control (Renney and Hughes, 1969; Hubbard, 1975; Chicoine, 1984), with residual effectiveness for two to four years following treatment (Renney and Hughes, 1969; Ali, 1984; Chicoine, 1984). Several other herbicides, including 2,4-D, 2,4-D amine, 2,4-D ester, dicamba, and MCPA have been tested for knapweed control (Renney and Hughes, 1969; Ali, 1984; Chicoine, 1984). Dicamba (Furrer and Fertig, 1965) 2,4-D amine (Chicoine, 1984; Furrer and Fertig, 1965), 2,4-D (Ali, 1984), and 2,4-D ester (Renney and Hughes, 1969; Furrer and Fertig, 1965) can provide effective short-term control, but have very little residual effectiveness.

In spite of their proven effectiveness against knapweed, herbicides have some limitations for use on rangeland. Short-lived herbicides like 2,4-D and dicamba are very inconvenient, because repeated applications are needed until the seed reserve in the soil is exhausted. Picloram, with its slower rate of decomposition, requires less follow-up spraying, but its cost is prohibitive to many ranchers. In addition, Harris and Cranston (1979) point out that many native forbs, which may be important for wildlife, are often killed by herbicides.

Despite these problems, herbicides have beneficial qualities that favor their use on grasslands. Several studies (Scifres and Halifax, 1972; Chicoine, 1984; O'Sullivan and Kossatz, 1984b; Scotter, 1975) have shown that most grass species are highly tolerant of the herbicides used on knapweed. Forage grasses can therefore increase production quite soon after knapweed removal. Chicoine (1984) found that grass production increased 200% to

500% following knapweed control with picloram. Renney and Hughes (1969), also using picloram, found that grass production increased 2- to 10-fold after knapweed control. Sheley et al. (1984) found that picloram applied with fertilizer resulted in several times as much grass production as picloram alone.

Another possible advantage of herbicides lies in their chemical instability. The herbicides are degraded by natural environmental processes (Johnsen and Martin, 1983; Scifres et al. 1977; Pik et al. 1977; Scifres et al. 1971a; Scifres et al. 1971b), so there should be no buildup of chemicals that could cause environmental damage.

Advantages of Pre-Treatment Burning

Burning prior to herbicide application could increase herbicide effectiveness for knapweed control, and subsequent plant growth. Standing litter intercepts some herbicide, which may be degraded before reaching live knapweed or the soil surface. Litter removal allows a more effective overall coverage of growing plants and the soil surface. By getting more herbicide on knapweed and into the soil, the effectiveness of a given rate of herbicide should increase.

A second advantage is that spring burning followed by spring rains should provide unusually warm and moist conditions, enhancing seed germination (Vogl, 1974). By increasing knapweed seed germination, and then applying herbicide to kill the seedlings, fewer viable seeds should remain in the soil. By reducing the seed reserve, reinfestation should be less of a problem, so less follow-up spraying should be needed.

A final advantage of burning is that ash on the soil provides a flush of available nutrients (Vogl, 1974). These nutrients may act to fertilize the site, improving conditions for remaining plants.

Picloram

Picloram effectively controls most broadleaf weeds (Anonymous, 1983a). Most grasses are resistant to picloram (Anonymous, 1983a; Scotter, 1975; O'Sullivan and Kossatz, 1984b; Scifres and Halifax, 1972), although some grasses have reduced growth (Scifres and Halifax, 1972) and very young seedlings of others may be damaged (Arnold and Santelmann, 1966) if picloram is applied at higher rates or successively over several years as with leafy spurge (Euphorbia esula) control. Picloram affects most broadleaf crops, except for species of the family Brassicaceae (Anonymous, 1983a). Picloram can be absorbed through foliage and roots and is translocated throughout the plant (Bovey and Mayeux, 1980; Anonymous, 1983a; Sharma et al. 1971). Sharma et al. (1971) found that high relative humidity increased the penetration of picloram into the leaves of Canada thistle (Cirsium arvense).

Environmental degradation of picloram occurs primarily through photodecomposition. Microbial degradation in the soil also occurs (Fryer et al. 1979; Herbicide handbook, 1983), and some herbicide may be lost through leaching in course textured soils (Merkle, Bovey, and Davis, 1967). The half-life of picloram in the soil varies from one month to four years, depending on the environmental conditions (Pik et al. 1977).

Photodecomposition results from exposure of picloram to ultraviolet radiation. Johnsen and Martin (1983) found that 95% of the picloram residues left on exposed surfaces of foliage, rock, and soil had decomposed after four days. The rate of decomposition is also related to elevation (Johnsen and Martin, 1983), with more rapid degradation at higher elevations.

Degradation by microbes varies, depending on the nature of the microbes, and conditions in the soil that affect their activity (Hamaker et al. 1967). Microbial decomposition increases with adequate water, higher temperature, and higher organic matter content (Herbicide handbook, 1983; Fryer et al. 1979).

In general, most of the picloram that is applied to a site is lost from the soil profile (Fryer et al. 1979; Scifres et al. 1971b; Scifres et al. 1977) and from affected broadleaf species (Scifres et al. 1971a) within a few weeks to a year after application. Evidence has shown that most of the picloram remains in the upper few inches of the soil until it is decomposed (Scifres et al. 1971b; Hamaker et al. 1967), with little removed from the site in run-off water (Goring and Hamaker, 1971).

<u>Clopyralid</u>

Clopyralid has proven most active against members of the Polygonaceae, Fabaceae, and Asteraceae families, with high tolerance shown by the Poaceae and Brassicaceae (Anonymous, 1985). Jacoby et al. (1981) found no evidence of grass injury following treatment with clopyralid.

Like picloram, clopyralid is absorbed via leaves and roots of plants, and is translocated through the plant (Haagsma, 1975; Devine and Born, 1985; Bovey and Mayeux, 1980). O'Sullivan and Kossatz (1984a) and Haagsma (1975) found that plants that are actively growing absorb more herbicide than plants in the flowering stage. Plants growing under conditions of high relative humidity ($\geq$ 95%) absorbed about twice as much herbicide as those growing at low relative humidity (about 40%) (O'Sullivan and Kossatz, 1984a).

Soil microbes are the primary agents of clopyralid degradation (Pik et al. 1977; Haagsma, 1975), with little if any photodecomposition occurring (Anonymous, 1983a) The average half-life is 12 to 70 days (Anonymous, 1983a), with degradation increasing as soil moisture and temperature increase, and decreasing with higher organic matter content (Pik et al. 1977). Pik et al. (1977) found that cold and dry conditions drastically reduced decomposition of clopyralid, and that decomposition continued to be relatively slow after overwintering in the soil.

Clopyralid has proven to be effective against such species as Canada thistle (O'Sullivan and Kossatz, 1984a; Devine and Born, 1985; O'Sullivan and Kossatz, 1982; Whitesides and Appleby, 1978; Turnbull and Stephenson, 1985; Keys, 1975), wild buckwheat (<u>Polygonum convolvulus</u>) (Keys, 1975), Russian thistle (<u>Salsola kali</u>) (Keys, 1975), and honey mesquite (<u>Prosopis juliflora</u>) (Bovey and Mayeux, 1980; Jacoby et al. 1981).

The herbicide induces an auxin-type response in plants (Haagsma, 1975), but the exact physiological activity is unknown

(Anonymous, 1983a). Neither plants nor animals are known to metabolize clopyralid, and when ingested by animals, the compound is rapidly excreted, with no accumulation in any animal tissues (Haagsma, 1975).

Metsulfuron methyl

Metsulfuron methyl has residual, broad spectrum activity for broadleaf weeds and is absorbed into plants through foliage and roots (Anonymous, 1983b). Species from several families, including the Brassicaceae, Asteraceae, Polygonaceae, Caryophyllaceae, and Boraginaceae, have shown susceptibility to this herbicide (Warner et al. 1986).

The herbicide is most stable when the pH is above seven, and possesses a laboratory half-life of approximately two to three weeks. Degradation of metsulfuron methyl occurs primarily by acid hydrolysis and microbial activity (Nelson, 1986).

Roberts and Bond (1984) found that the herbicide is most active when applied pre-emergence or early post-emergence. Metsulfuron methyl has been shown to kill or suppress many species, including Canada thistle, Russian thistle, and Kochia (*Kochia* spp.) (Warner et al. 1986). Metsulfuron methyl activity is promoted by warm, moist conditions following treatments, while cold, dry conditions may reduce or delay activity (Anonymous, 1986).

Materials and Methods

Site Description

Study plots were established on three sites during the spring of 1985. One site was located about 65 km northeast of Missoula on the Blackfoot-Clearwater game range (T15N R14W S21, alluvial flat receiving approximately 40.5 cm of annual precipitation). The second site was on the Threemile game range about 40 km south of Missoula (T38N R18W S17, abandoned farmland receiving approximately 32 cm of annual precipitation). The third site was about 3 km south of Lolo Montana (T11N R20W S10, grazed pasture receiving approximately 32 cm of annual precipitation). Common characteristics of the three sites include:

1. Dense and relatively uniform spotted knapweed infestations.
2. Originally grassland.
3. Many native forbs present, allowing comparison of herbicide selectivity.
4. Sandy-loam surface horizon.

Appendix 1 contains a list of all grasses, forbs, and shrubs found on the three sites (Dorn, 1984).

Herbicides

The herbicides used in this study were picloram, clopyralid, picloram + clopyralid, and metsulfuron methyl. picloram, clopyralid, and the picloram + clopyralid mixture were applied in liquid form, using water as a carrier.

The metsulfuron methyl was a 60% dry flowable formulation

which formed a suspension in water. Continuous agitation was maintained to keep the herbicide in suspension. Surfactant was added in a 0.25 v/v ratio to promote adherence of the herbicide to foliage.

Treatments

Treatments consisted of 15 herbicide applications and a control. The herbicide treatments were: picloram, clopyralid, and the picloram + clopyralid mixture applied at 0.14 kg, 0.28 kg, and 0.42 kg of active ingredient (a.i.) per hectare. The metsulfuron methyl was applied at 0.035 kg, 0.07 kg, and 0.14 kg a.i./hectare. These rates of metsulfuron methyl were expected to have approximately equal activity as the 0.14 kg, 0.28 kg, and 0.42 kg rates of the other herbicides (Warner, 1984). Additional treatments consisted of spraying 0.14 kg a.i./ha of clopyralid and picloram + clopyralid, and 0.035 kg a.i./ha of metsulfuron methyl on plots that had been burned to remove plant litter.

Burning

Plots were burned during April of 1985. Black lines were burned first to provide a firebreak around the border of each plot. Fuel in the plot was then ignited on the upwind side using a drip-torch. Patches that did not burn were reignited, so that most of the standing litter was consumed.

Measurements of relative humidity and wind speed were taken at the time of burning. Relative humidity was measured using wet and dry bulb temperature and relative humidity tables, and ranged from 20% to 30% at the time of burning. Wind speed was measured using a Dwyer animometer, and ranged from 0 to 15 km/hour.

Herbicide Application

Herbicides were applied during the first two weeks of May, 1985, using a boom sprayer. The weather was calm and sunny at all three sites, so herbicide drift was negligible.

The sprayer's boom swath was 8 feet 4 inches wide, so three or four swaths (depending on the site) were sprayed in each treatment plot. Adjacent swaths may have had some spray overlap. All data samples were collected from the middle of the sprayer swaths to avoid these areas.

Sampling Procedures

Annual standing crop (kg/ha) was measured by clipping current years vegetation near ground level. Sample plots with an area of 0.5 m^2 were used. Vegetation was clipped, oven-dried at 65 °C and weighed. The most common species were clipped separately. Less common grass species were grouped, with the relative weights of each species being estimated. Spotted knapweed was clipped and weighed separately. Forbs were clipped as a group with two exceptions: 1) All forbs clipped during the summer of spraying were clipped as a group, but the relative weight of each species on each plot was estimated, and 2) silky lupine (Lupinus sericeus) and northwest cinquefoil (Potentilla gracilis) were common on threemile game range, so the relative weights of these two species were estimated as a percent of total forb production.

Plots were clipped three months and 15 months after spraying. Plots to be clipped were randomly located within each treatment, but were in the center of the sprayer swaths to avoid

areas of herbicide overlap. Four samples in each treatment plot were clipped.

Clipping was informative for grass and spotted knapweed, but did not provide much information concerning the response of most forbs. Two additional measurements were used to better quantify the response of various forbs.

The first measurement was of occurrence of early spring forbs. Each plot was visually inspected, and all forb species occurring in each treatment plot were noted. This gave an estimation of how some of these early forbs were affected.

Forb density was measured during the late spring of 1986, approximately 13 months after spraying. Density was measured by counting the number of plants of each species in randomly-placed 0.2 m^2 plots. A total of 20 density plots were measured in each treatment of each block.

Experimental design

A randomized complete block experimental design was used. Blocking was used to adjust for perceived differences in vegetation, primarily grass composition, and slight differences in aspect, that occurred on the study sites. Treatments were randomly assigned to the plots within a block, so that each treatment was replicated once in each block. Appendix 2 diagrams the treatment arrangement for each site.

Treatment plot size differed slightly between sites. Plots on the Blackfoot site were 12.15 m wide by 36.5 m long. Those on the Lolo and Threemile sites were 9.12 m wide by 36.5 m long.

Statistical Analysis

Statistical analyses were performed on production and density data using an analysis of variance for a randomized complete block design (Ott, 1984). Additional analyses consisted of a 3 X 3 factorial to compare spotted knapweed and total grass standing crop, and knapweed density, on the 0.14 kg, 0.28 kg, and 0.42 kg rates of picloram, picloram + clopyralid, and clopyralid. For species that had significant differences between treatments (alpha = 0.05 for spotted knapweed and total grass, alpha = 0.10 for other species), Duncan's new multiple range test was used to compare means (Ott,1984). Appendix 3 contains a list of the data means that were compared.

All data were transformed before analysis of variance using the following transformation: $y=\log(y+1)$. This transformation was used to make the sample variances more homogeneous.

Results and Discussion

Two occurrences during 1985 should be considered while interpreting these results. First, the spring and summer of 1985 were extremely dry, with precipitation only one-quarter to one-half of normal. Appendices 4 and 5 contain monthly precipitation data for 1985 and 1986. In addition to the drought, two of the sites received some grazing during 1985.

Because of the dry conditions, most plants grew very little during the three months between herbicide spraying and data collection in 1985. Under normal circumstances, a large percentage of a grasses' roots die and are replaced each year.

The lack of growth (photosynthesis) during the dry period probably resulted in a considerable loss of root biomass, because root growth would not have been sufficient to replace those that died (Stoddart et al. 1975). During 1986, grasses may have used most of their available energy to increase root production at the expense of leaf growth. For this reason, the standing crop increase in response to knapweed removal may be less than normal through 1986.

A second occurrence was that the Threemile site and two blocks on the Clearwater site were grazed by trespass cattle during the summer (Threemile) and fall (Clearwater) of 1985. The burned plots were observed to be most heavily grazed, but all picloram, picloram + clopyralid, and clopyralid treatments were grazed. The drought and grazing reduced the ability of forage species to increase growth following knapweed removal. Therefore, standing crop increases found in this study were probably less than could be expected under better post-spraying conditions.

Spotted Knapweed Response

Picloram, clopyralid, and picloram + clopyralid treatments killed all knapweed plants that were growing at the time of spraying. No knapweed growth was observed on any of these treatments after spraying during 1985, but approximately 30 kg/ha of spotted knapweed standing crop was present at the time of spraying (Figure 1). Picloram has been used previously to control spotted knapweed, with 0.28 kg/ha providing excellent initial control (Chicoine, 1984).

Metsulfuron methyl did not reduce spotted knapweed standing crop on the Clearwater site, but at Lolo, knapweed standing crop was reduced by the 0.035 kg + burn, the 0.07 kg, and the 0.14 kg treatments. Visual observations indicated that metsulfuron methyl stunted spotted knapweed growth, but was not lethal.

Fifteen months after spraying, 0.28 kg and 0.42 kg of picloram continued to provide excellent spotted knapweed control, reducing the standing crop by 98% to 100% on all sites (Figures 2-4). No spotted knapweed grew on the 0.42 kg treatments. The 0.14 kg rate of picloram continued to control 99% of the knapweed on the Lolo site (Figure 2), but lost effectiveness on the Clearwater (68% control) and Threemile (83% control) sites (Figures 3-4).

These results can be compared with findings by Chicoine (1984) who found that 0.14 kg and 0.28 kg of picloram provided 100% control of spotted knapweed 14 months after treatment. Similarly, Renney and Hughes (1969) obtained 100% control after 12 months on plots treated with 0.28 kg of picloram.

The relative increase in knapweed production on the 0.14 kg picloram treatments at Clearwater was much larger than that found on the other sites. In addition, comparisons were made between corresponding rates of picloram, picloram + clopyralid, and clopyralid. The relative increase in knapweed growth was much greater with 0.14 kg of picloram than on the same rate of the other herbicides. Because the results for 0.14 kg of picloram at Clearwater were so inconsistent, it was believed that a mistake was made at the time of spraying and that the actual application

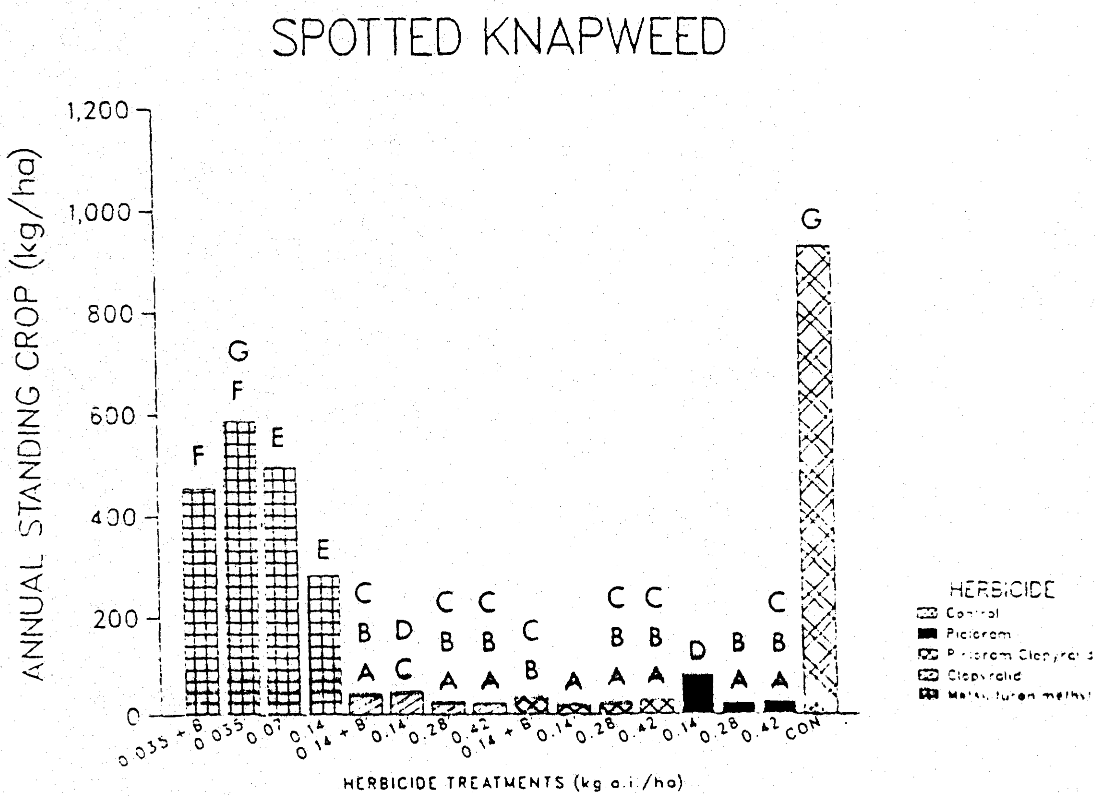

Figure 1. Spotted knapweed standing crop (kg/ha), Lolo site, three months after treatment.

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[1] Means with the same letter are not significantly different at the 0.05 probability level.

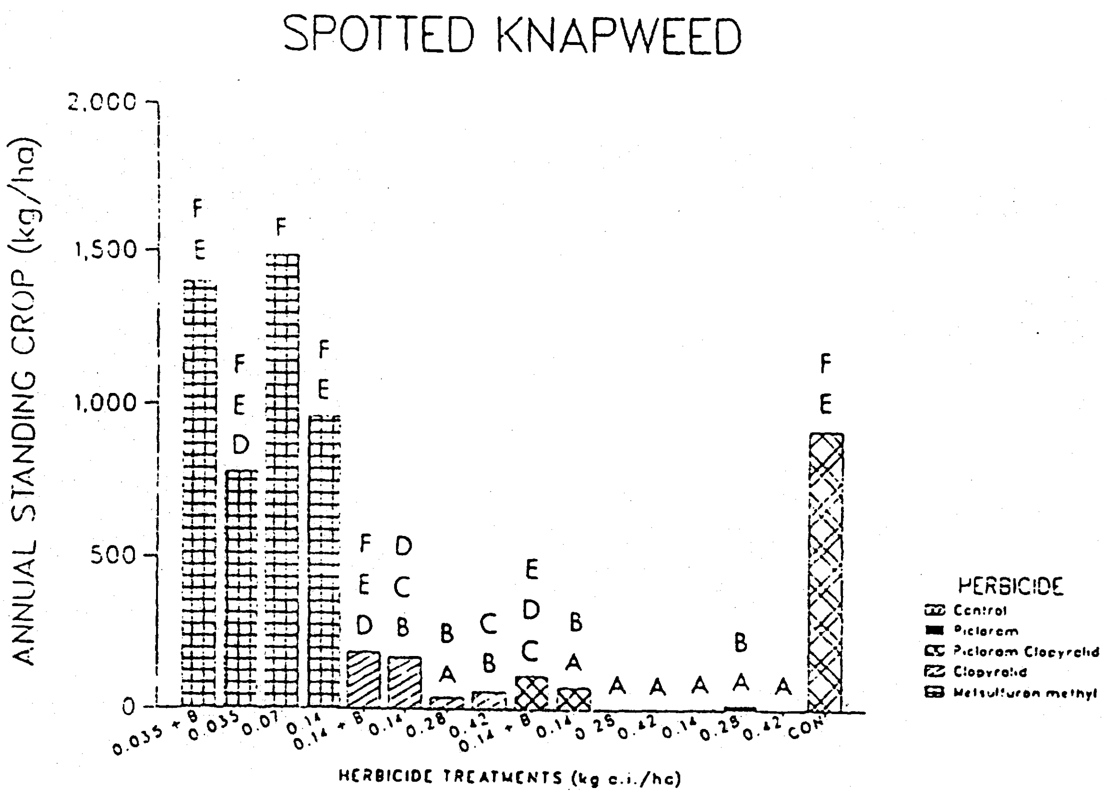

Figure 2. Spotted knapweed standing crop (kg/ha), Lolo site, 15 months after treatment.

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[2] Means with the same letter are not significantly different at the 0.05 probability level.

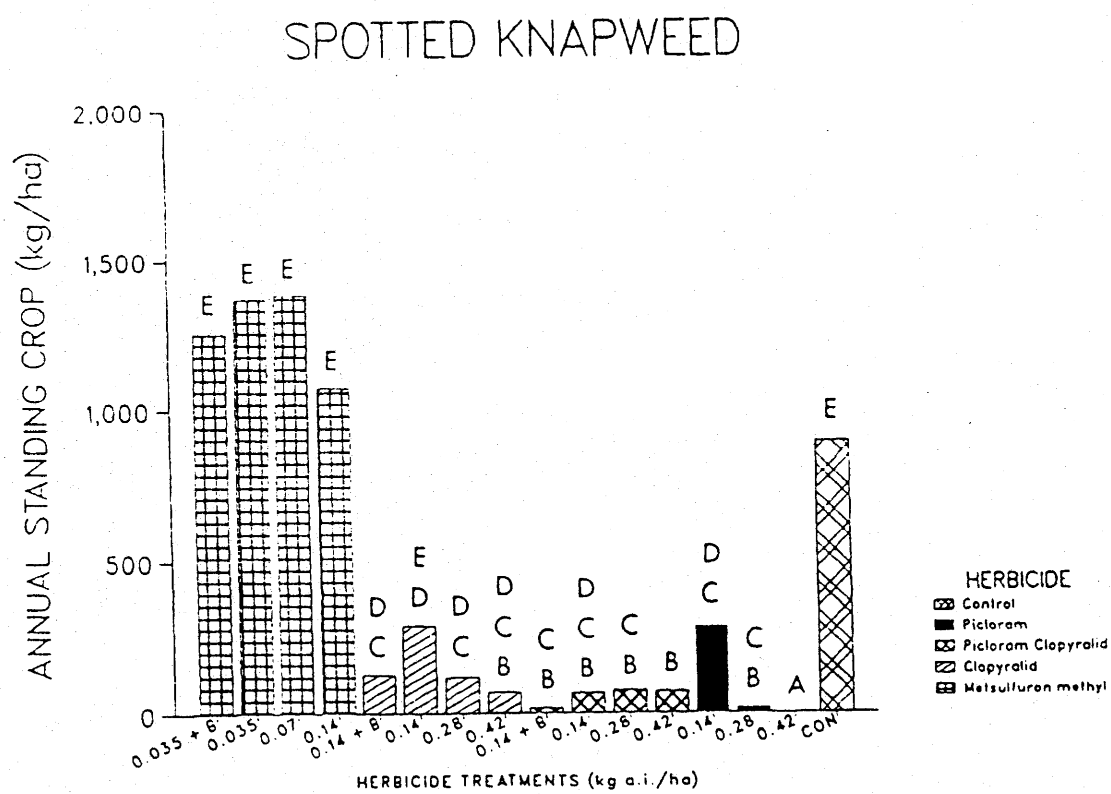

Figure 3. Spotted knapweed standing crop (kg/ha), Clearwater site, 15 months after treatment.

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[3] Means with the same letter are not significantly different at the 0.05 probability level.

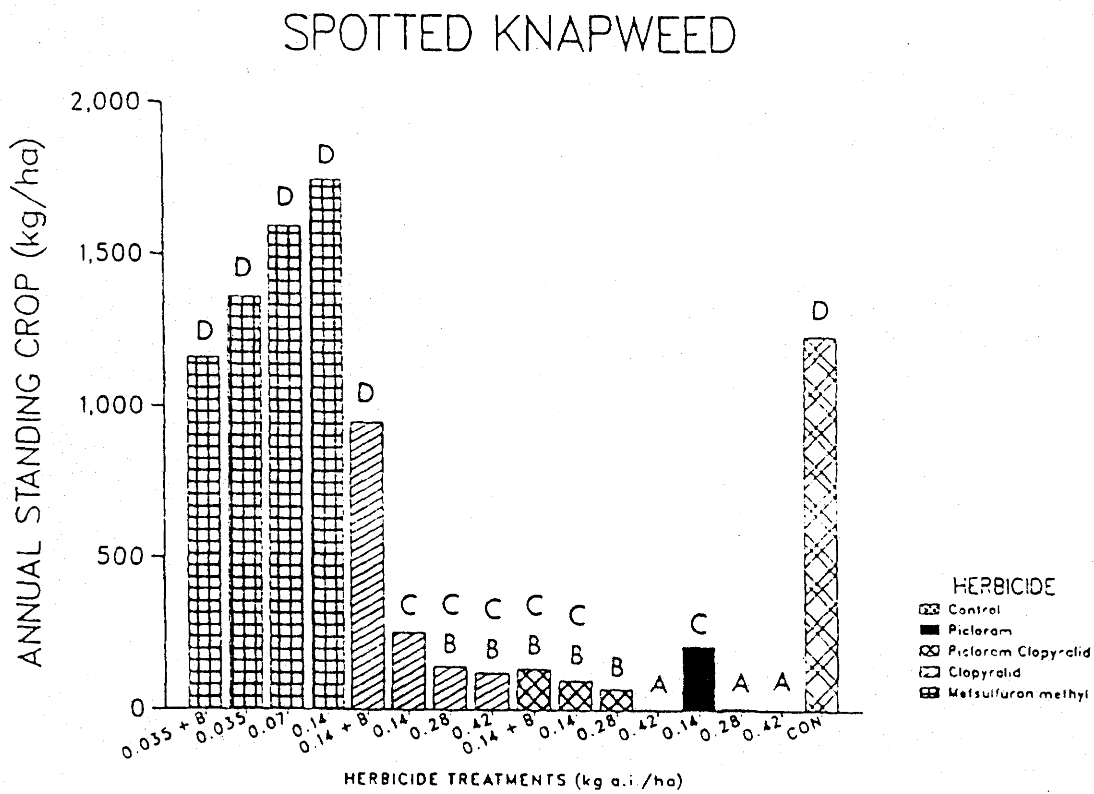

Figure 4. Spotted knapweed standing crop (kg/ha), Threemile site, 15 months after treatment.

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4 Means with the same letter are not significantly different at the 0.05 probability level.

rate was less than 0.14 kg/ha.

Picloram + clopyralid and clopyralid allowed some spotted knapweed growth, particularly the 0.14 kg rates. The 0.28 kg and 0.42 kg rates of picloram + clopyralid gave comparable results, reducing knapweed standing crop by 91% at Clearwater to 100% at Lolo. Knapweed control by 0.14 kg of picloram + clopyralid was similar for burned and unburned treatments, with knapweed standing crop reduced by 88% to 98% over the three sites.

Clopyralid alone was slightly less effective than when mixed with picloram. Clopyralid at 0.28 kg to 0.42 kg provided 87% to 96% control on all three sites. On these treatments, all invading knapweed plants were seedlings. However, on plots treated with 0.14 kg of clopyralid, some mature spotted knapweed plants and many seedlings were present.

Reinvasion by knapweed was most pronounced on the burned treatments at Threemile (Figure 4). This increase in knapweed probably resulted in part from the heavy grazing that occurred at Threemile during the summer of 1985. From these results, it appears that grazing disturbance may greatly increase the reinfestation rate once a herbicide loses effectiveness.

Spotted knapweed density after 12 months gave additional information concerning herbicide residual effectiveness. No knapweed plants were found on plots treated with 0.42 kg of picloram on any site (Figures 5-7). The 0.28 kg rate was nearly as effective, providing 100% control on the Lolo site (Figure 5), 99% control at Threemile (Figure 6), and 96% control on the Clearwater site (Figure 7). Picloram applied at 0.14 kg/ha

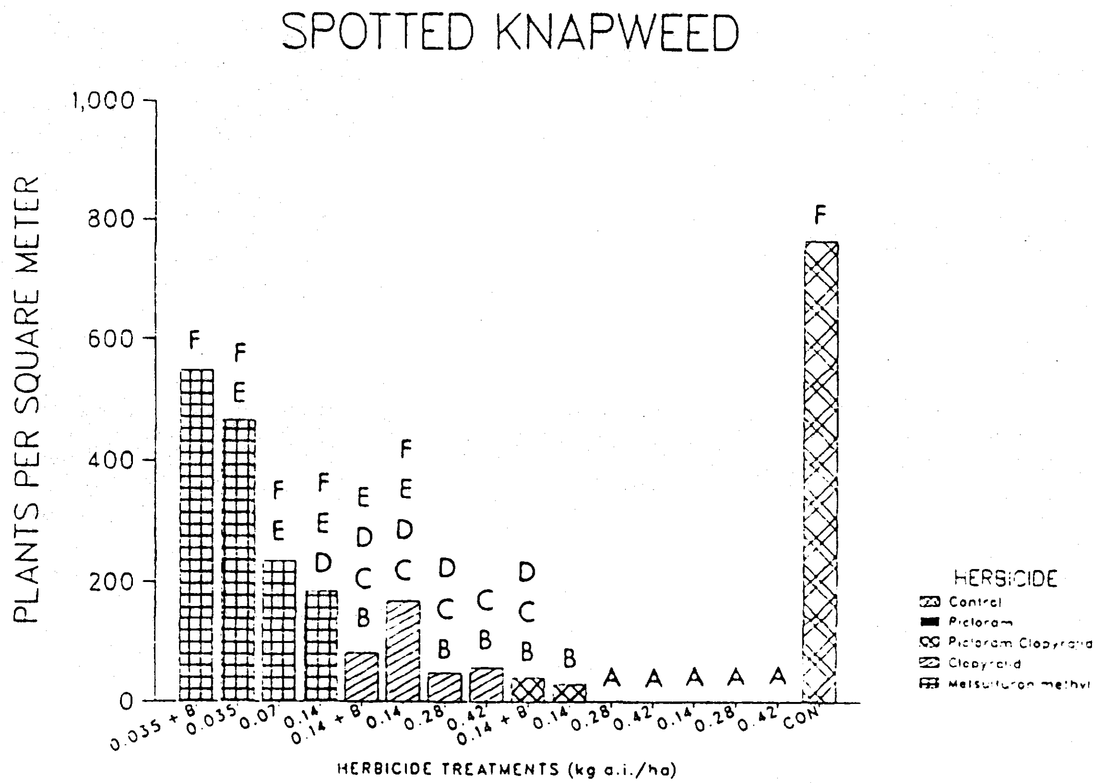

Figure 5. Spotted knapweed density (plants/m^2), Lolo site, 13 months after treatment.

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[5] Means with the same letter are not significantly different at the 0.05 probability level.

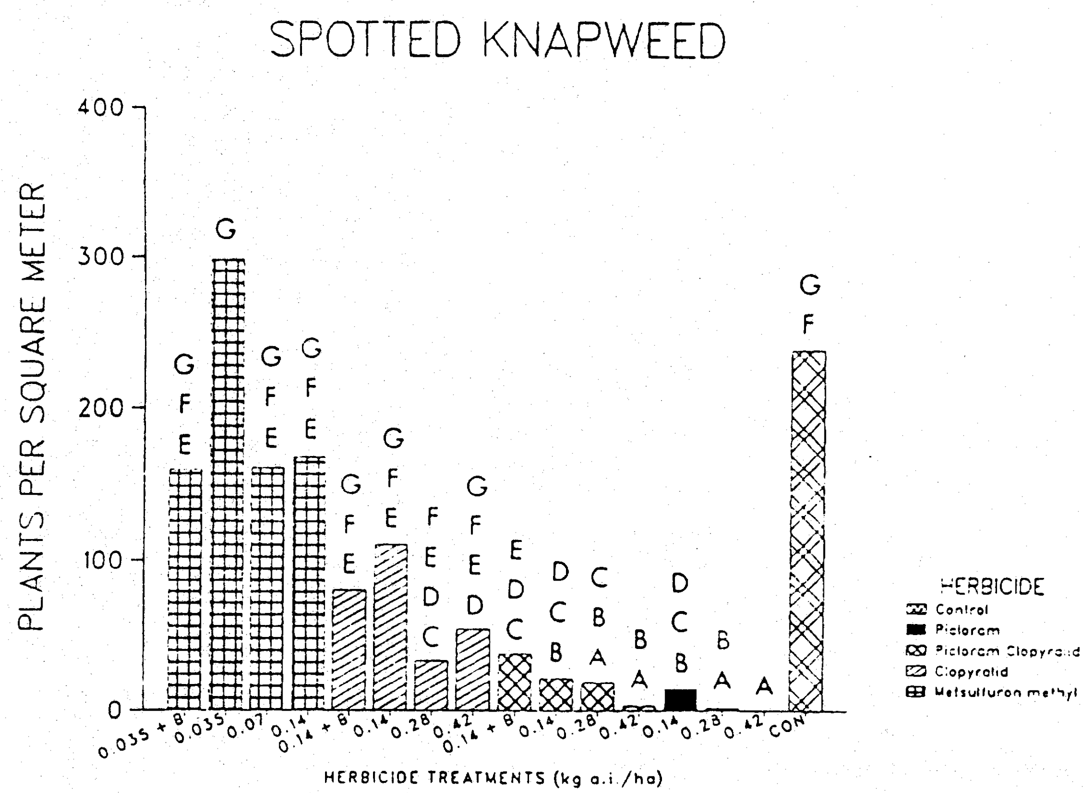

Figure 6. Spotted knapweed density (plants/m^2), Threemile site, 13 months after treatment.

[6] Means with the same letter are not significantly different at the 0.05 probability level.

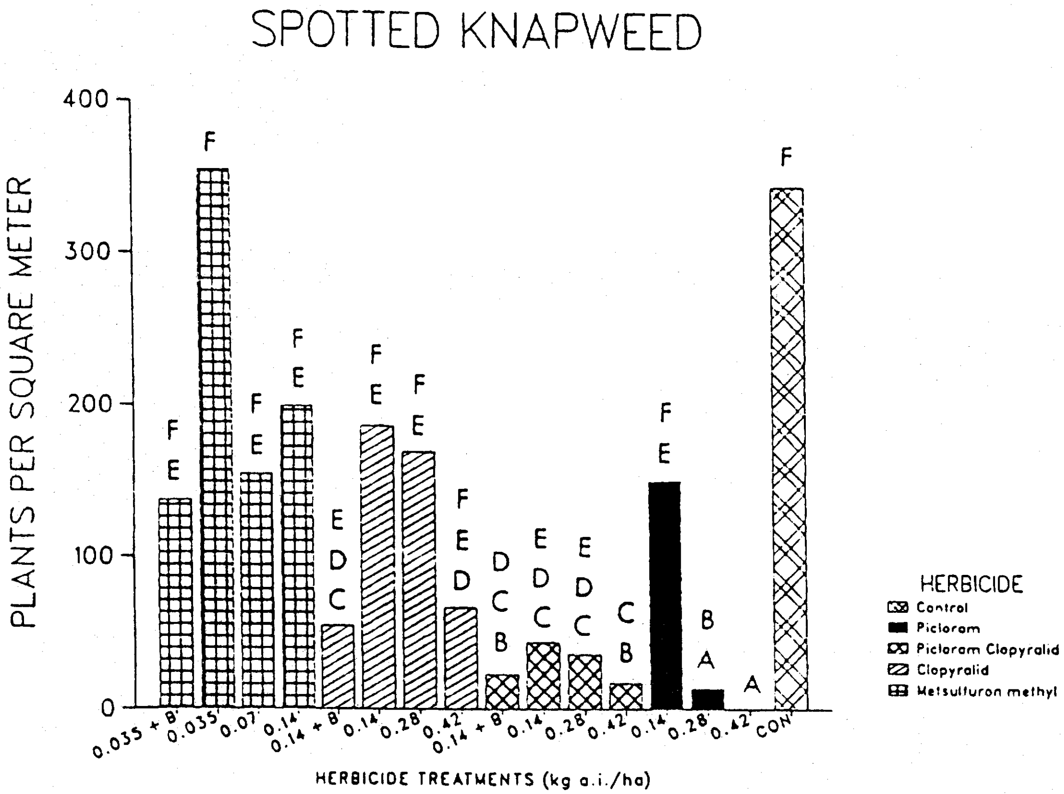

Figure 7. Spotted knapweed density (plants/m^2), Clearwater site, 13 months after treatment.

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[7] Means with the same letter are not significantly different at the 0.05 probability level.

maintained essentially 100% control at the Lolo site, with only 1.3 knapweed plants per m^2. Residual activity provided about 94% control at Threemile, with 14.7 plants per m^2 compared to 238.6 plants per m^2 for the control. Essentially all knapweed plants growing on the above treatments were seedlings or rosettes, which should produce no seed until at least 1987 (Schirman, 1981). At the Clearwater site, 0.14 kg picloram was much less effective than on the other sites, averaging 151 spotted knapweed plants per m^2. Again, this lack of control compared to the other sites and compared to corresponding rates of the other herbicides indicates that the applied rates may have actually been less than 0.14 kg/ha.

In a previous study, Chicoine (1984) found that picloram gave similar results. Fourteen months after treatment, no mature spotted knapweed plants were found on 0.14 kg to 0.28 kg of picloram, although some seedlings were found on the 0.14 kg treatments.

Picloram + clopyralid treatments generally had more knapweed reinfestation than corresponding picloram treatments on all three sites (Figures 5-7). The one exception to this trend was on the Clearwater site, where 0.14 kg of picloram had more reinvasion than the 0.14 kg picloram + clopyralid + burn and 0.14 kg picloram + clopyralid treatments (Figure 7). Knapweed density was reduced 95% to 100% by 0.42 kg of picloram + clopyralid, 90% to 100% by the 0.28 kg rate, and 84% to 96% by the 0.14 kg and 0.14 kg + burn treatments. There was no difference in knapweed density between burned and unburned plots.

Clopyralid generally provided less residual control than picloram and picloram + clopyralid. Spotted knapweed seedlings were present and appeared vigorous on all clopyralid treatments. Reinfestation ranged from about 60 plants/m^2 on the 0.42 kg rate, to more than 160 plants per m^2 on some 0.14 kg treatments. Many of these plants would produce flowers during their second year of growth. Based on the rate of seedling reinvasion, respraying would apparently be necessary every second year to maintain control of spotted knapweed using clopyralid.

Metsulfuron methyl did not reduce knapweed density compared to the control. Mature spotted knapweed plants were common and flowered successfully on all metsulfuron methyl treatments.

General comparisons indicate that equal rates of picloram, picloram + clopyralid, and clopyralid are most effective for spotted knapweed control in the order listed. This conclusion is based on the ability of picloram to prevent knapweed reinvasion to a greater degree than equal rates of picloram + clopyralid and clopyralid. All three herbicides gave the most effctive knapweed control when applied at 0.42 kg/ha. Metsulfuron methyl causes little impairment of spotted knapweed growth, at least under the conditions in which it was applied here.

The herbicides were generally most effective at the Lolo site, especially in terms of preventing reinfestation. This may reflect the lack of post spraying disturbance at Lolo compared to the Clearwater and Threemile sites.

<u>Response by Grass Species</u>

Annual standing crop was measured individually for rough

fescue, _bluebunch wheatgrass_, Idaho fescue (_Festuca idahoensis_), threadleaf sedge (_Carex filifolia_), prairie junegrass (_Koeleria macrantha_), and Kentucky bluegrass (_Poa pratensis_) to determine how each species responded to spotted knapweed control. Total forage production was also measured on each site. The standing crop of prairie junegrass, Kentucky bluegrass, and total forage production increased following spotted knapweed removal. Visual observations indicated that the other species increased in size following knapweed removal.

Prairie junegrass production increased on all picloram, picloram + clopyralid, and clopyralid treatments (Figures 8 and 9). On the Clearwater site, junegrass standing crop increased 400% to 800% compared to the control (Figure 8), while on the Lolo site, production increased 400% to 1600 percent (Figure 9).

Kentucky bluegrass response to knapweed removal was measured at Threemile, where Kentucky bluegrass was the dominant grass species. As with prairie junegrass, Kentucky bluegrass production increased on all treatments that initially controlled knapweed (Figure 10). Standing crop increases ranged from 180% on the burned plots to 350% on 0.42 kg picloram treatments.

Total grass standing crop increased on all sites following knapweed removal. At Lolo, total grass standing crop increased by 240% to 360% following knapweed control (Figure 11).

Results were similar, but less consistent at Clearwater and Threemile. Grass standing crop generally increased on picloram, picloram + clopyralid, and clopyralid treatments. Metsulfuron methyl treatments did not have increased grass production.

On the Clearwater site, 0.28 kg and 0.42 kg of clopyralid, 0.42 kg of picloram + clopyralid, and all picloram treatments resulted in increased grass standing crop. These increases ranged from 200% to 375% over the control (Figure 12). At Threemile (Figure 13), grass production did not increase on the burned plots. All other treatments that initially controlled knapweed had corresponding increases in total grass standing crop. These increases ranged from 190% to 290% over the control, which produced 710 kg/ha.

Similar, but slightly greater increases in grass standing crop (300% to 400%) were found by Chicoine (1984) 14 months after knapweed removal. Considering the droughty conditions, and the grazing that occured at Threemile and Clearwater, these results seem very comparable.

Several grass species did not have increased standing crop compared to the control, but did appear larger and more vigorous where knapweed was controlled. These species include bluebunch wheatgrass, rough fescue, Idaho fescue, threadleaf sedge, onespike oatgrass (Danthonia unispicata), and Canada bluegrass (Poa compressa). These grasses exhibited extreme variability between samples, because plants were often widely separated, and differed considerably in size. This variability may have been one reason for the lack of statistical significance. Canada bluegrass in particular increased growth dramatically, but was only present in small patches, so only a few samples were collected.

Another possibility is that the bunch grasses were still

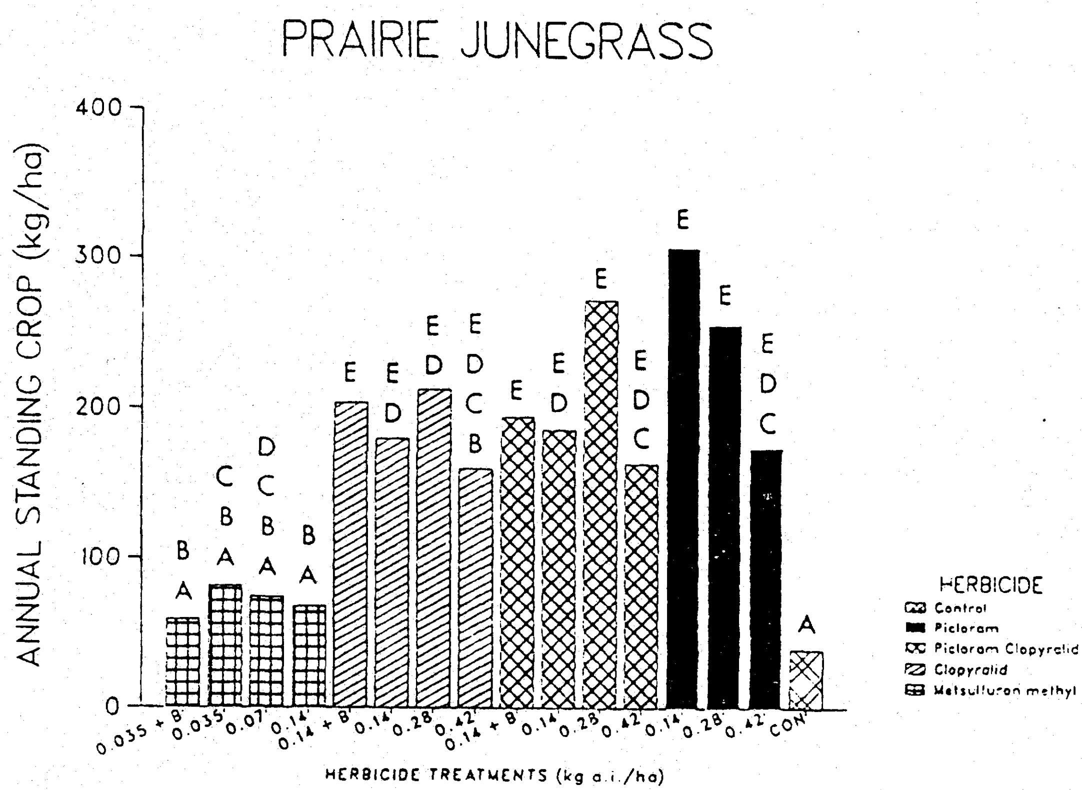

Figure 8. Prairie junegrass standing crop (kg/ha), Lolo site, 15 months after treatment.

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[8] Means with the same letter are not significantly different at the 0.10 probability level.

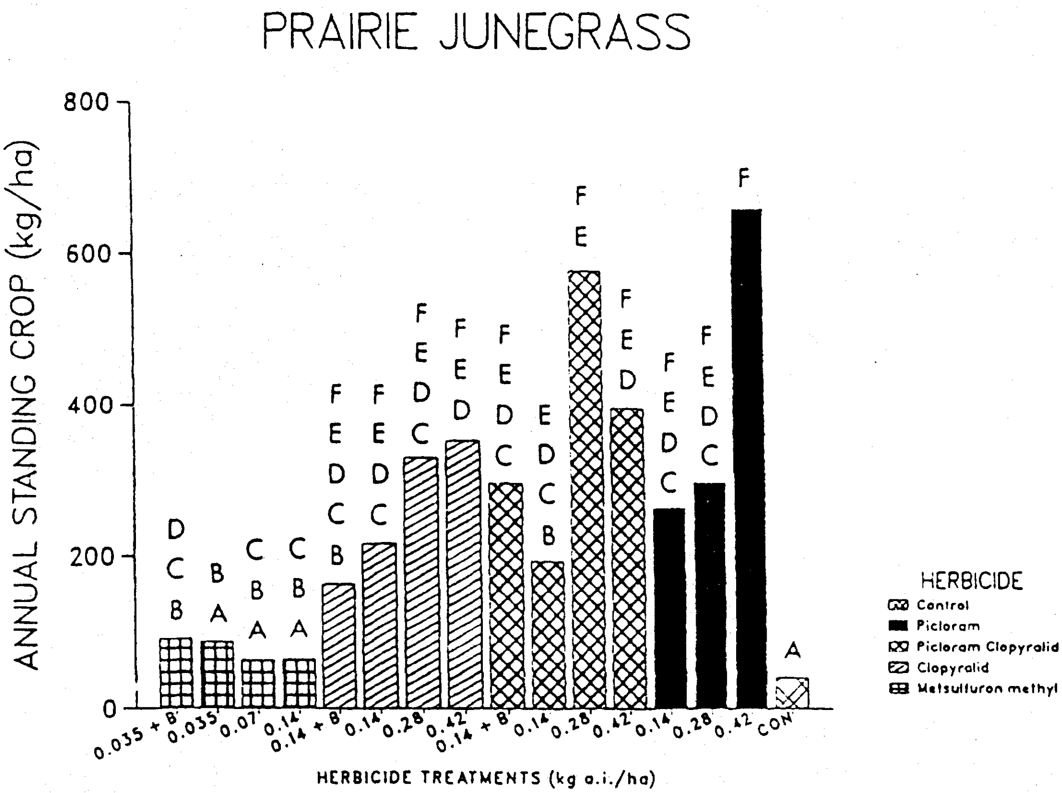

Figure 9. Prairie junegrass standing crop (kg/ha), Clearwater site, 15 months after treatment.

[9] Means with the same letter are not significantly different at the 0.10 probability level.

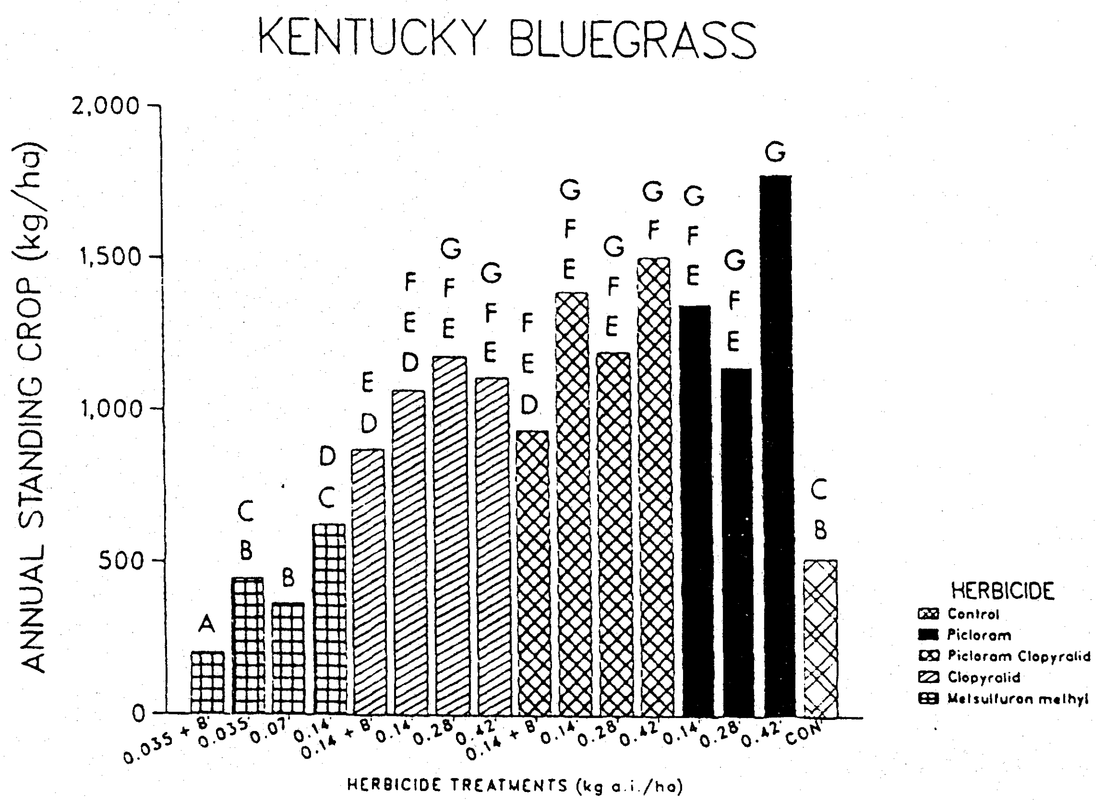

Figure 10. Kentucky bluegrass standing crop (kg/ha), Threemile site, 15 months after treatment.

[10] Means with the same letter are not significantly different at the 0.10 probability level.

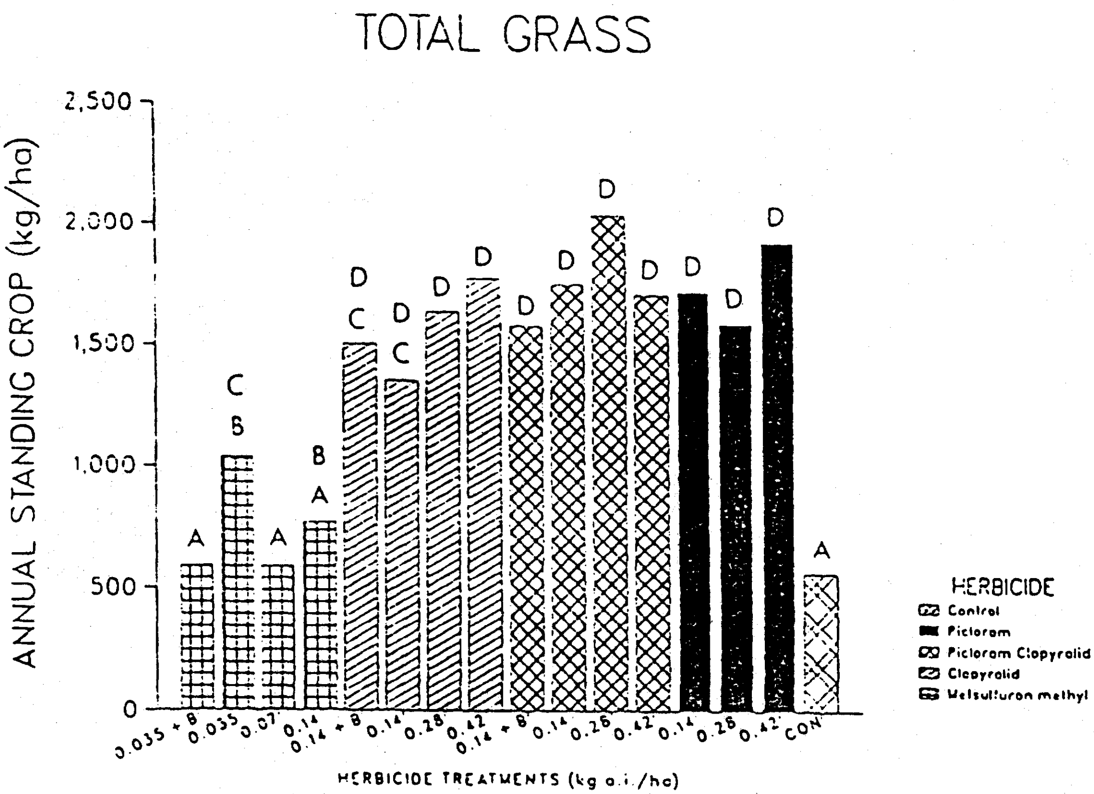

Figure 11. Total grass standing crop (kg/ha), Lolo site, 15 months after treatment.

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[11] Means with the same letter are not significantly different at the 0.05 probability level.

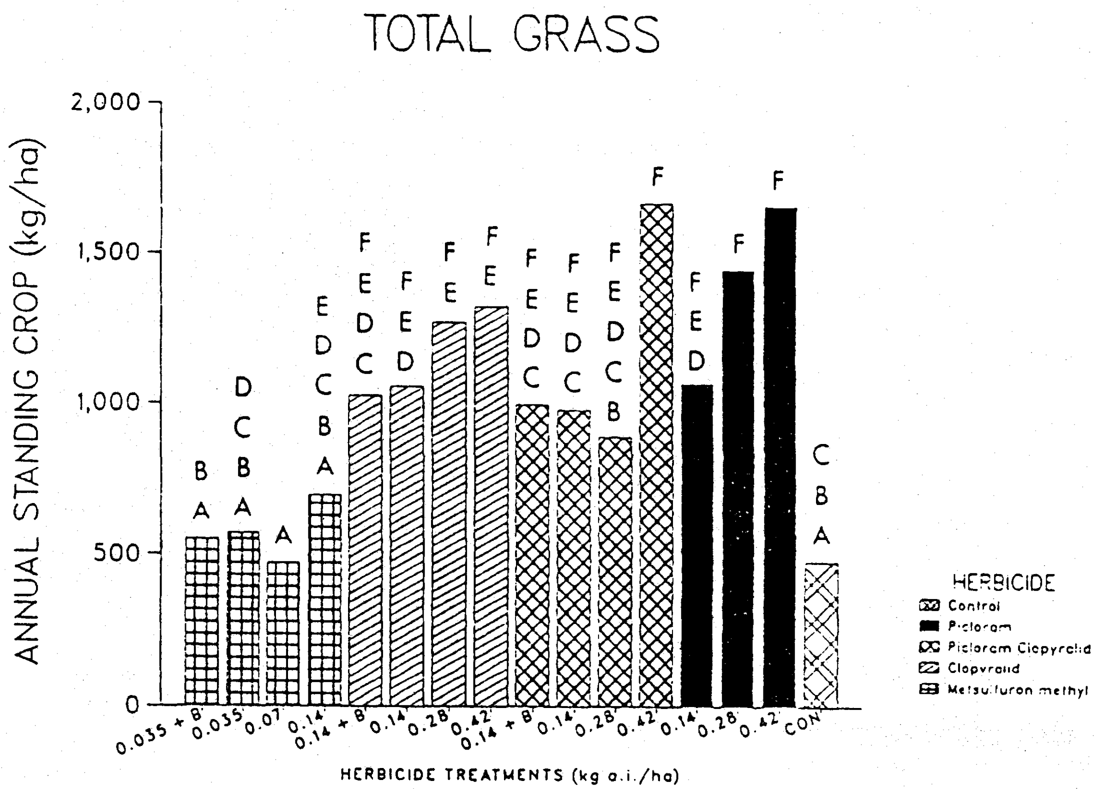

Figure 12. Total grass standing crop (kg/ha), Clearwater site, 15 months after treatment.

[12]Means with the same letter are not significantly different at the 0.05 probability level.

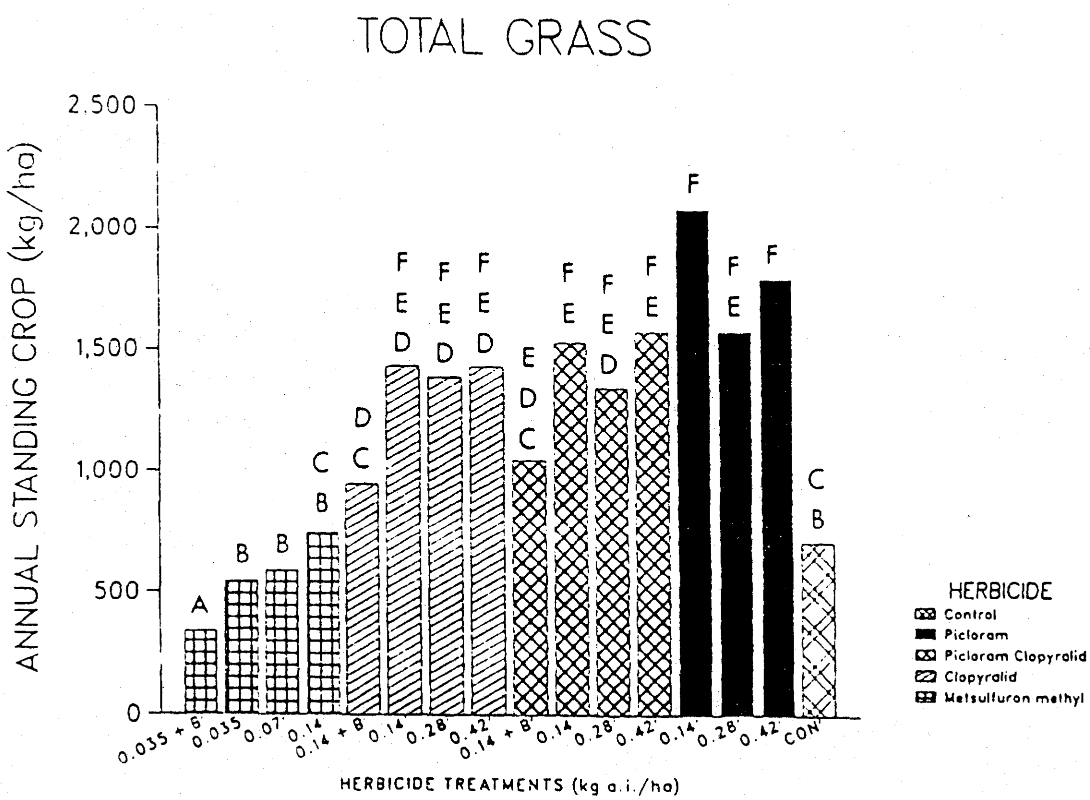

Figure 13. Total grass standing crop (kg/ha), Threemile site, 15 months after treatment.

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[13] Means with the same letter are not significantly different at the 0.05 probability level.

recovering from the previous year's drought. Herbage production may show a greater increase for these species during the 1987 growing season, at least on treatments that continue to control knapweed.

Herbicide Selectivity

A herbicide that kills spotted knapweed, but also kills many other forbs, would be ecologically and aesthetically harmful. Native forbs may improve site fertility (e.g. N_2 fixation by some species), recycle nutrients, help hold soil, are seasonally important in the diets of many animals, and are visually pleasing. For these reasons, herbicides to be applied on rangeland should be chosen for selectivity as well as ability to control the target weed.

Density measurements, observations on the sites, and standing crop measurements were used to assess the effect of each herbicide on several forb species that were present on one or more sites.

Apiaceae

The family Apiaceae was represented primarily by nineleaf lomatium (Lomatium triternatum) on the Clearwater site. Some large-fruited lomatium (L. macrocarpum) was also present. All herbicides reduced lomatium density to some extent (Figure 14).

Metsulfuron methyl caused the most damage. Lomatium density declined from a low of 97% on the 0.035 kg + burn treatment to 100% on the 0.14 kg application.

Compared to the control, picloram reduced the population at all applied rates. Plant density declined by 79% on the 0.14 kg

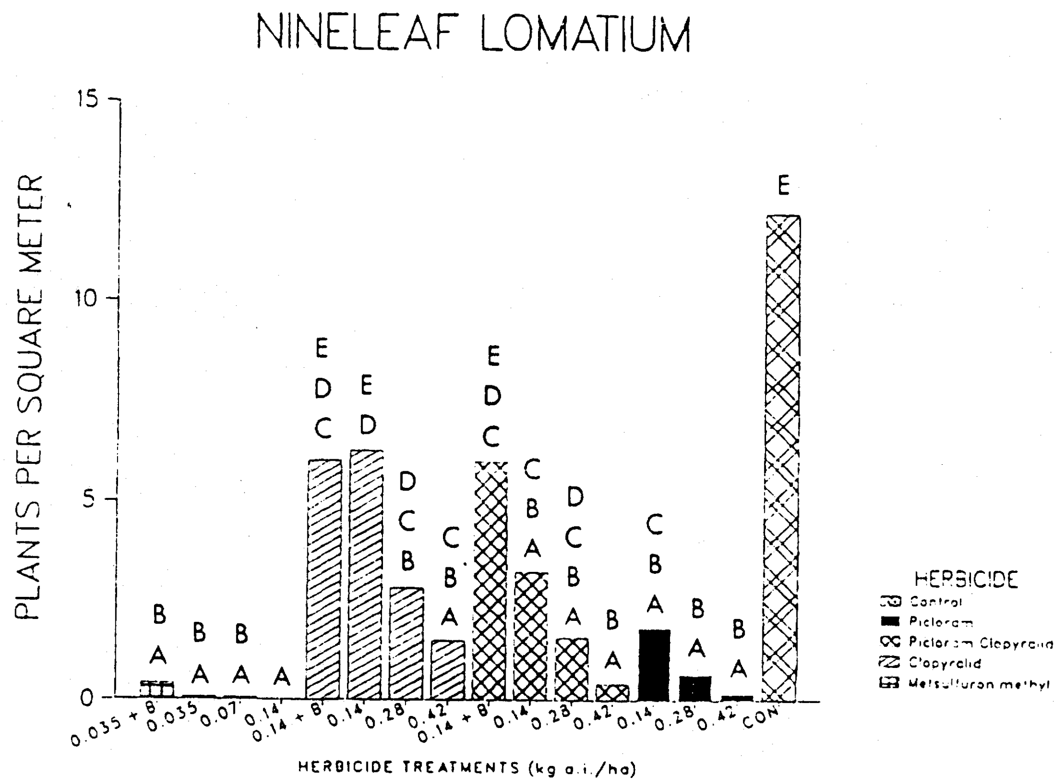

Figure 14. Nineleaf lomatium density (plants/m^2), Clearwater site, 13 months after treatment.

[14] Means with the same letter are not significantly different at the 0.10 probability level.

treatments, 92% on the 0.28 kg treatments, and 99% on 0.42 kg treatments.

Picloram + clopyralid and clopyralid were somewhat less damaging than picloram and metsulfuron methyl. Picloram + clopyralid applied to burned plots did not reduce lomatium density compared to the control, but the 0.14 kg, 0.28 kg, and 0.42 kg rates resulted in 72%, 86%, and 96% reductions, respectively.

Clopyralid applied at 0.14 kg did not reduce lomatium density; however, plant numbers declined by 77% on 0.28 kg of clopyralid, and 88% under the 0.42 kg rate.

Asteraceae

Picloram and clopyralid have been effective against several composite species, including Canada thistle and Russian knapweed (*C. repens*) (Laning, 1963; Haagsma, 1975; O'Sullivan and Kossatz, 1984b). Metsulfuron methyl has undergone less testing, but has also shown activity against some members of the Asteraceae (Warner et al. 1986).

Plant density for the family Asteraceae was analyzed for the Lolo and Clearwater sites, which supported many species from this family. Picloram, picloram + clopyralid, and clopyralid effects were similar to each other on the Clearwater site (Figure 15). The 0.14 kg treatments generally did not reduce Asteraceae numbers. Picloram and picloram + clopyralid at 0.28 kg reduced Asteraceae density by 85% to 89%, while the 0.42 kg rate of the three herbicides resulted in 93% to 98% fewer plants. Metsulfuron methyl reduced Asteraceae density at all rates, with

89% to 98% declines. Similar results for Asteraceae were found on the Lolo site (Figure 16), but the various treatments appeared to have relatively less effect than at the Clearwater site.

Several species from the Asteraceae were analyzed separately.

Density of western yarrow (Achillea millefolium) was reduced by all herbicides, with greater reductions occurring with higher herbicide rates (Figure 17). Metsulfuron methyl and picloram reduced western yarrow density by 93% to 100 percent. Picloram + clopyralid caused slightly less damage, with 78% to 99% reductions. Clopyralid was least damaging. No decline was found on the 0.14 kg + burn treatment, but the 0.14 kg, 0.28 kg, 0.42 kg treatments reduced yarrow density by 70%, 86%, and 98% respectively.

Rose pussytoes (Antennaria rosea) and small leaf pussytoes (A. parviflora) occurred on the Clearwater site. Pussytoes density was reduced on all picloram treatments (Figure 18). Metsulfuron methyl, picloram + clopyralid, and clopyralid reduced plant density at the higher rates, but did not cause significant reductions at low rates. Visual observations on the sites indicated that even these low rates reduced pussytoes density to some extent.

Arnica (Arnica fulgens) was very sensitive to metsulfuron methyl, which reduced plant density by 98% to 100% (Figure 19). The effects of picloram, picloram + clopyralid, and clopyralid were similar to each other, reducing arnica by 92% to 99% on the 0.42 kg rates. Lower rates did not significantly reduce arnica

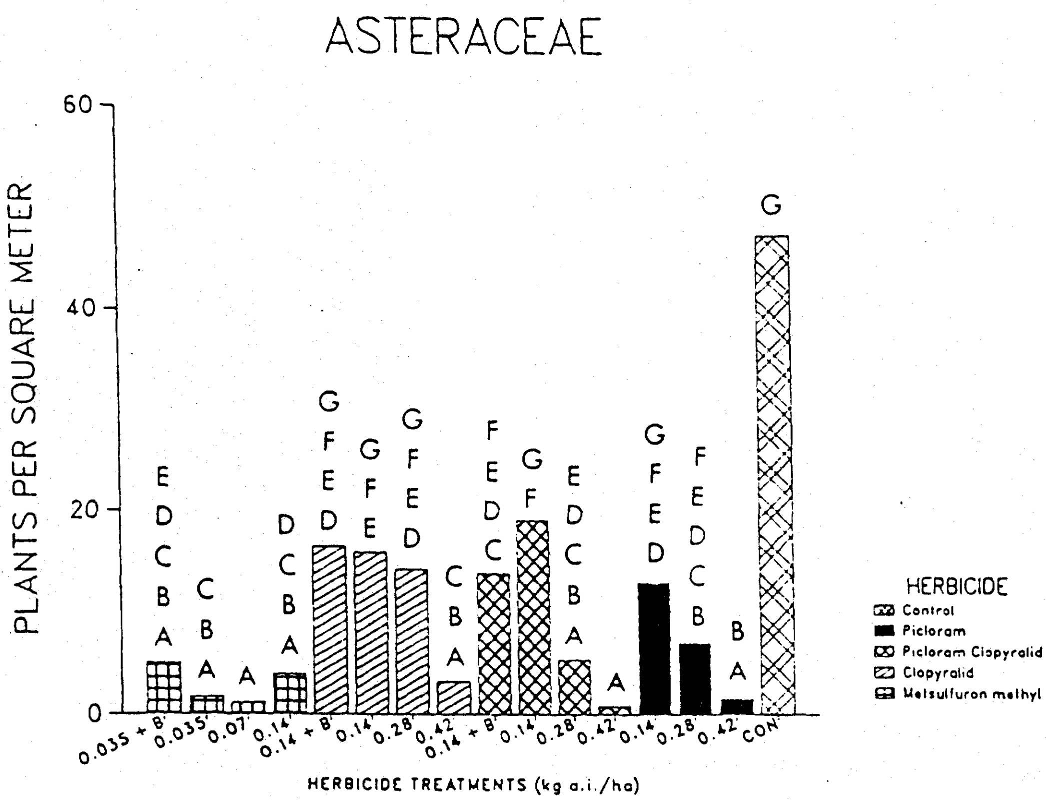

Figure 15. Density (plants/m^2) of all species from the Asteraceae, Clearwater site, 13 months after treatment.

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[15]Means with the same letter are not significantly different at the 0.10 probability level.

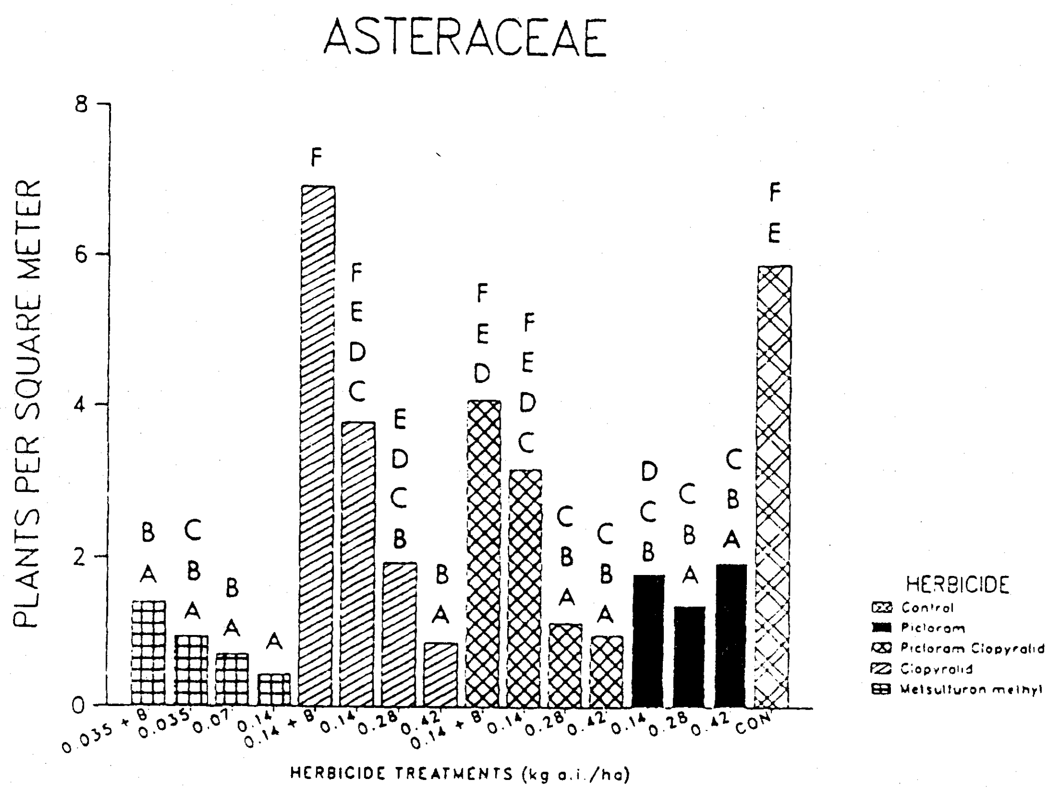

Figure 16. Density (plants/m^2) of all species from the Asteraceae, Lolo site, 13 months after treatment.

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[16] Means with the same letter are not significantly different at the 0.10 probability level.

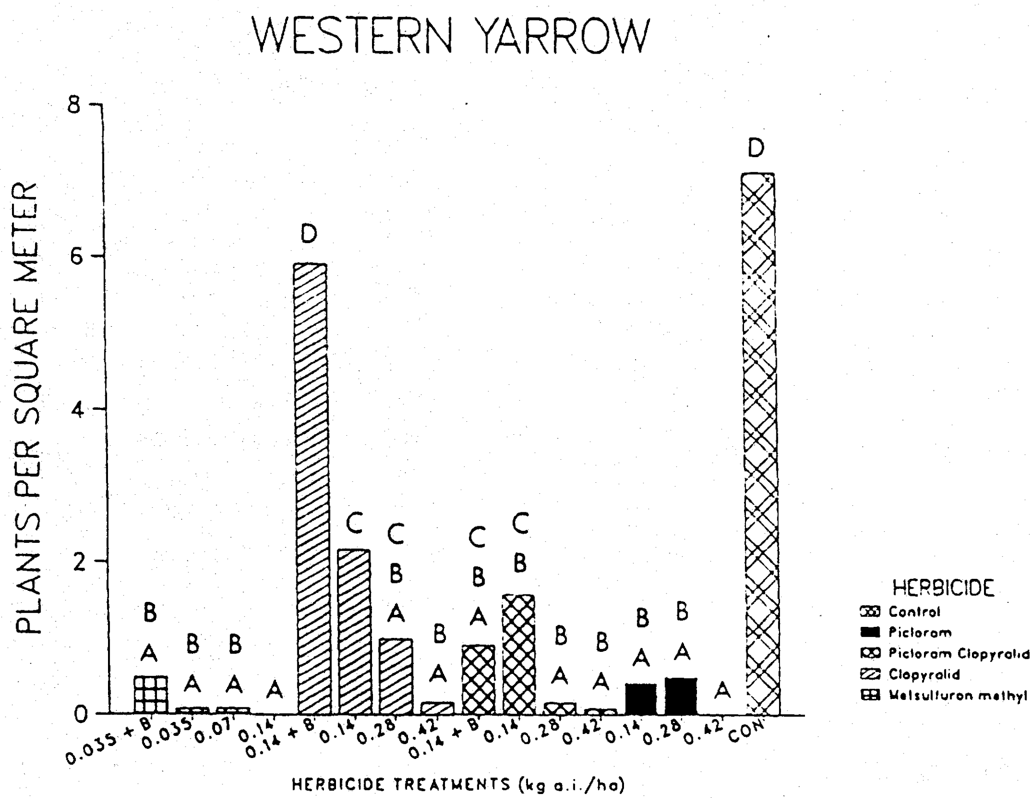

Figure 17. Western yarrow density (plants/m^2), Lolo site, 13 months after treatment.

[17]Means with the same letter are not significantly different at the 0.10 probability level.

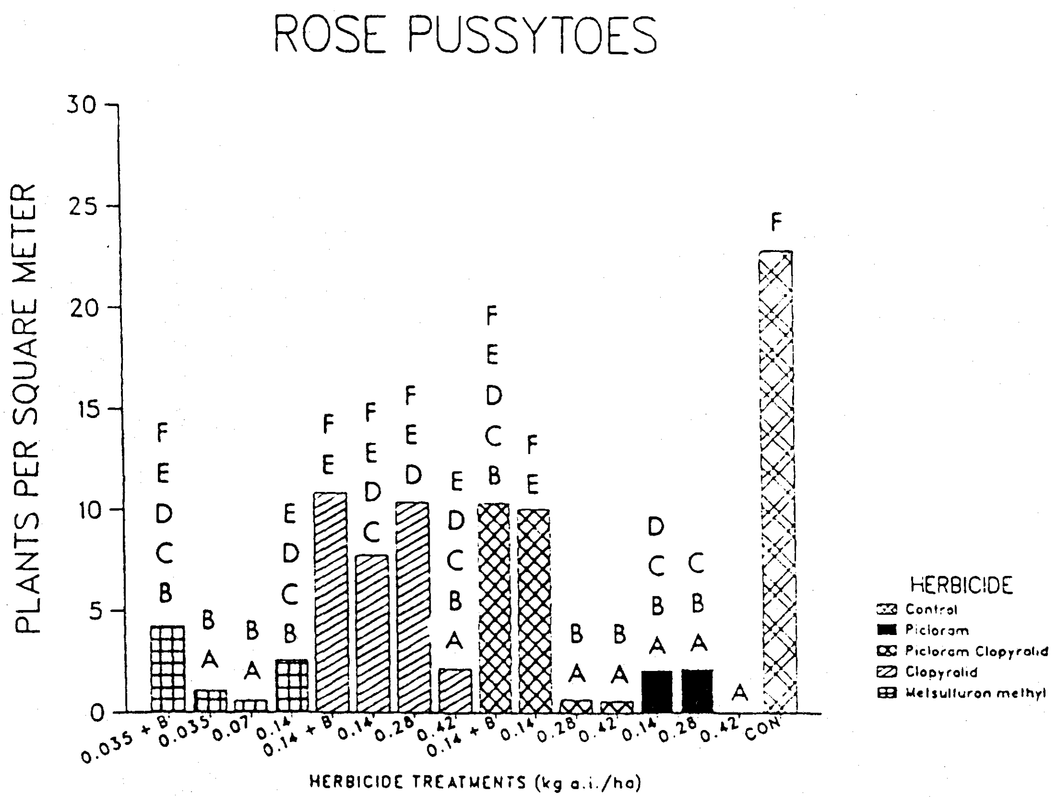

Figure 18. Rose pussytoes density (plants/m^2), Clearwater site, 13 months after treatment.

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[18]Means with the same letter are not significantly different at the 0.10 probability level.

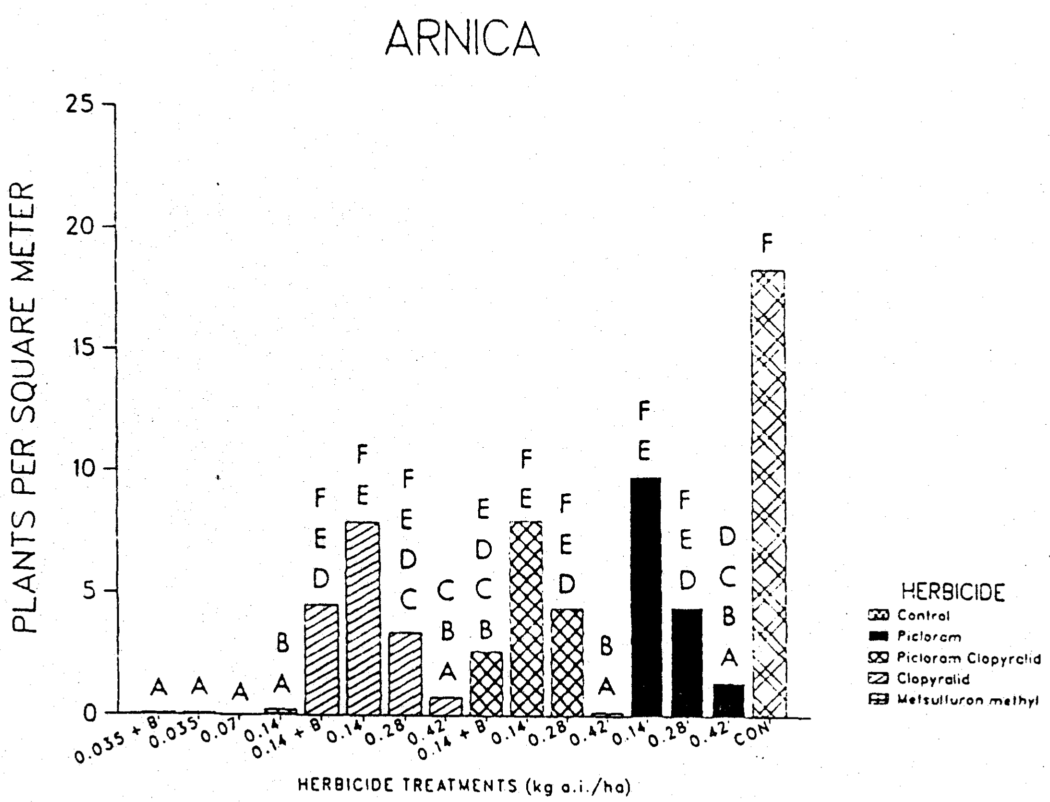

Figure 19. Arnica density (plants/m^2), Clearwater site, 13 months after treatment.

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[19]Means with the same letter are not significantly different at the 0.10 probability level.

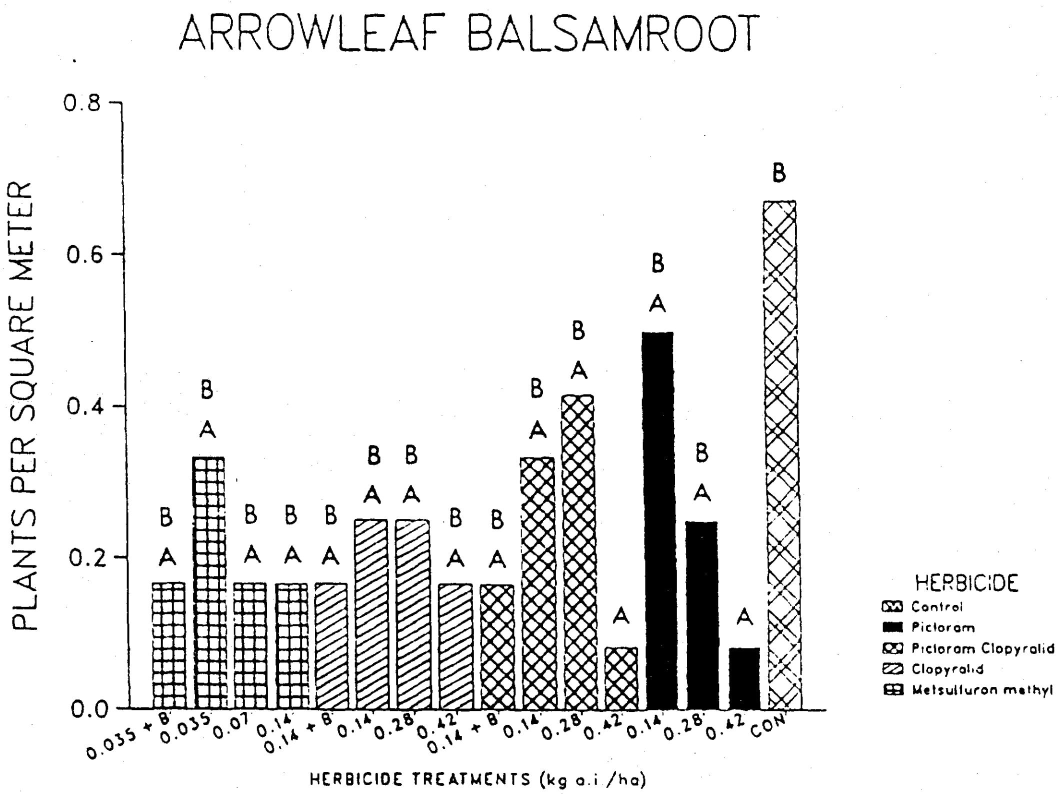

Figure 20. Arrowleaf balsamroot density (plants/m^2), Lolo site, 13 months after treatment.

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[20] Means with the same letter are not significantly different at the 0.10 probability level.

numbers, but visual observation on the sites, and the pattern of the sample means, indicated that all rates probably reduced plant density slightly to some extent.

Arrowleaf balsamroot (Balsamorhiza sagittata) density was less than the control on 0.48 kg of picloram and picloram + clopyralid (Figure 20). Balsamroot leaves appeared withered shortly after spraying on treatments containing picloram, but plants were present and vigorous on all treatments 12 months after spraying.

Oregon fleabane (Erigeron speciosus) was not reduced by any treatment compared to the control (Figure 21); however, two patterns in the data were evident. First, many more plants were found on burned treatments than on corresponding unburned plots. Second, although results were inconclusive, clopyralid and metsulfuron methyl seem to have reduced this species.

Field fluffweed (Filago arvensis) density was reduced by 0.28 kg and 0.42 kg of picloram (Figure 22). No other treatments decreased fluffweed density.

Picloram, picloram + clopyralid, and clopyralid did not reduce blanketflower (Gaillardia aristata) (Figure 23). Although not causing significant reductions, metsulfuron methyl was considered harmful to blanketflower based on the average number of plants on metsulfuron methyl treatments ($0.06/m^2$) compared with the average growing on all other treatments ($1.89/m^2$).

Golden-aster (Heterotheca villosa) density was not reduced by any of the herbicides (Figure 24). Visual observations indicated that metsulfuron methyl and clopyralid caused golden-

aster no apparent harm; however, few healthy plants were noted on picloram treatments.

Goldenrod (Solidago missouriensis) was present in large numbers on the 0.14 kg and 0.14 kg + burn treatments of clopyralid and picloram + clopyralid (Figure 25), indicating that these treatments did not harm this species. Results for the other treatments were inconclusive, with none causing significant reductions.

Boraginaceae

Slender forget-me-not (Myosotis micrantha) density was significantly reduced only on 0.28 kg and 0.42 kg Picloram treatments (Figure 26). Metsulfuron methyl and clopyralid did not appear to harm this species.

Warner et al. (1986) found that 0.0042 kg/ha of metsulfuron methyl was able to suppress fiddleneck tarweed (Amsinckia spp.) and corn gromwell (Lithospermum arvense), two other members of the Boraginaceae.

Brassicaceae

No herbicide treatments had statistically significant effects on this family as a whole, and no pattern was evident in the data (Figure 27). Density measurements for Holboell rockcress (Arabis holboellii), spring draba (Draba verna), woods draba (D. nemorosa), and tumblemustard (Sisymbrium altissimum) were analyzed individually. Tumblemustard appeared to be affected by metsulfuron methyl and picloram (Figure 28), which appear to reduce tumblemustard's ability to increase in response to knapweed removal. Several species have previously shown

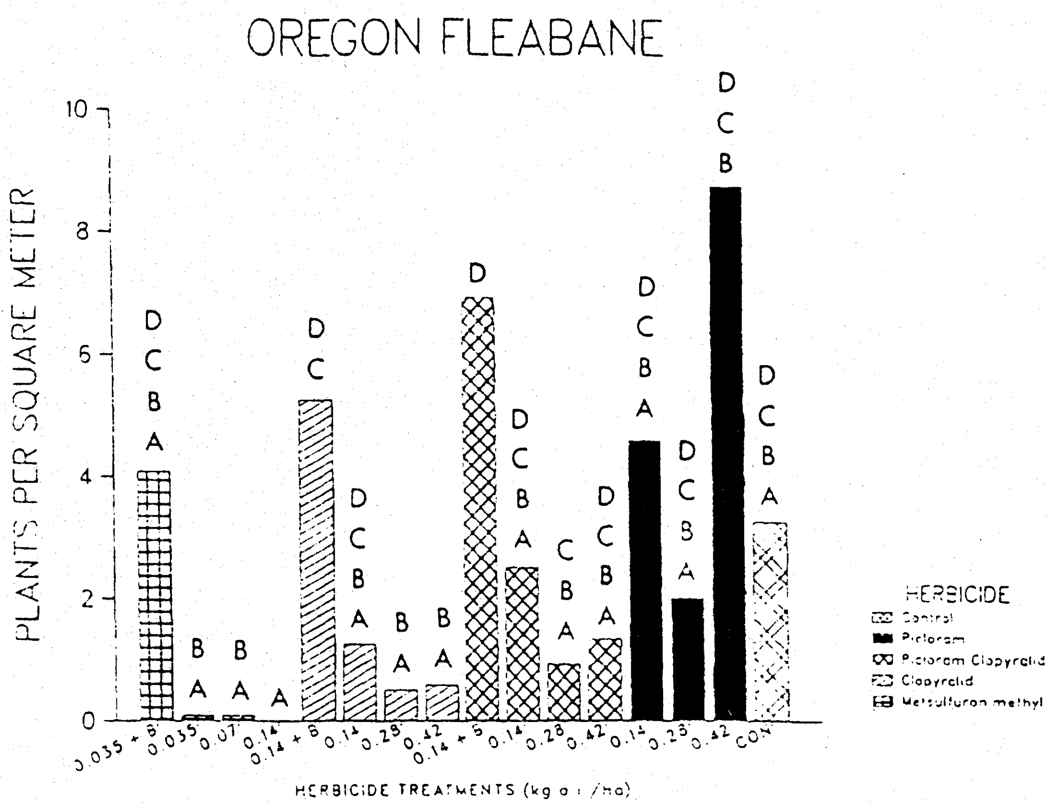

Figure 21. Oregon fleabane density (plants/m^2), Lolo site, 13 months after treatment.

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[21]Means with the same letter are not significantly different at the 0.10 probability level.

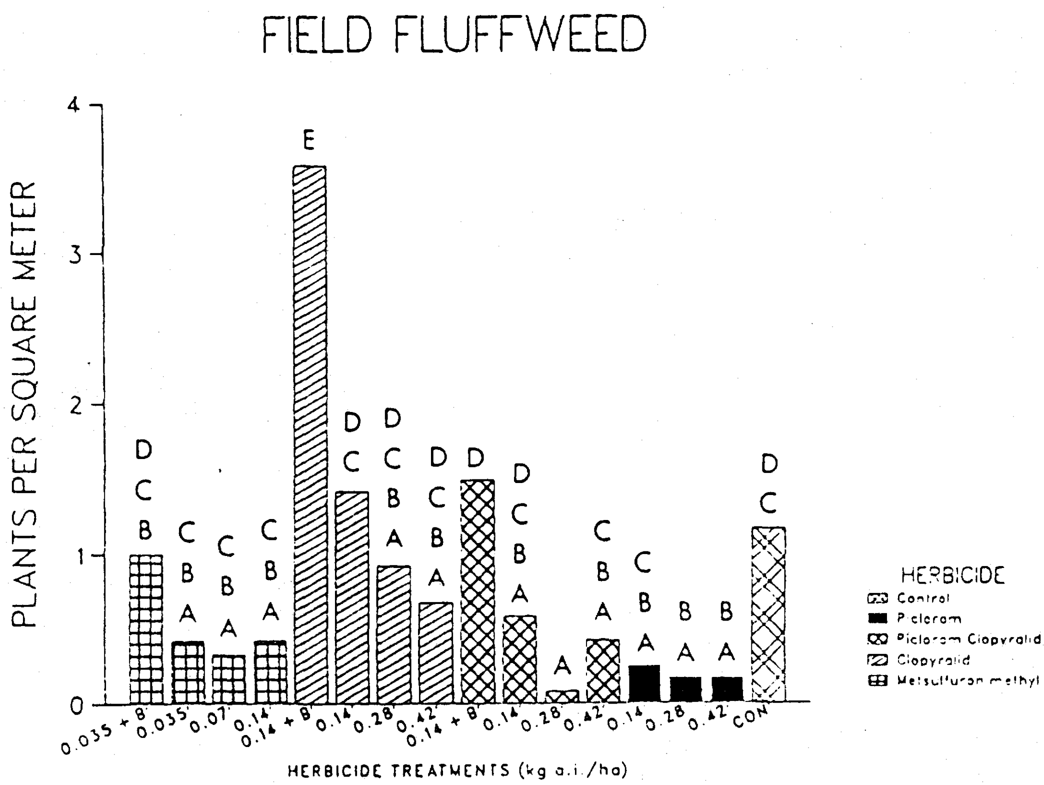

Figure 22. Field fluffweed density (plants/m^2), Threemile site, 13 months after treatment.

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[22]Means with the same letter are not significantly different at the 0.10 probability level.

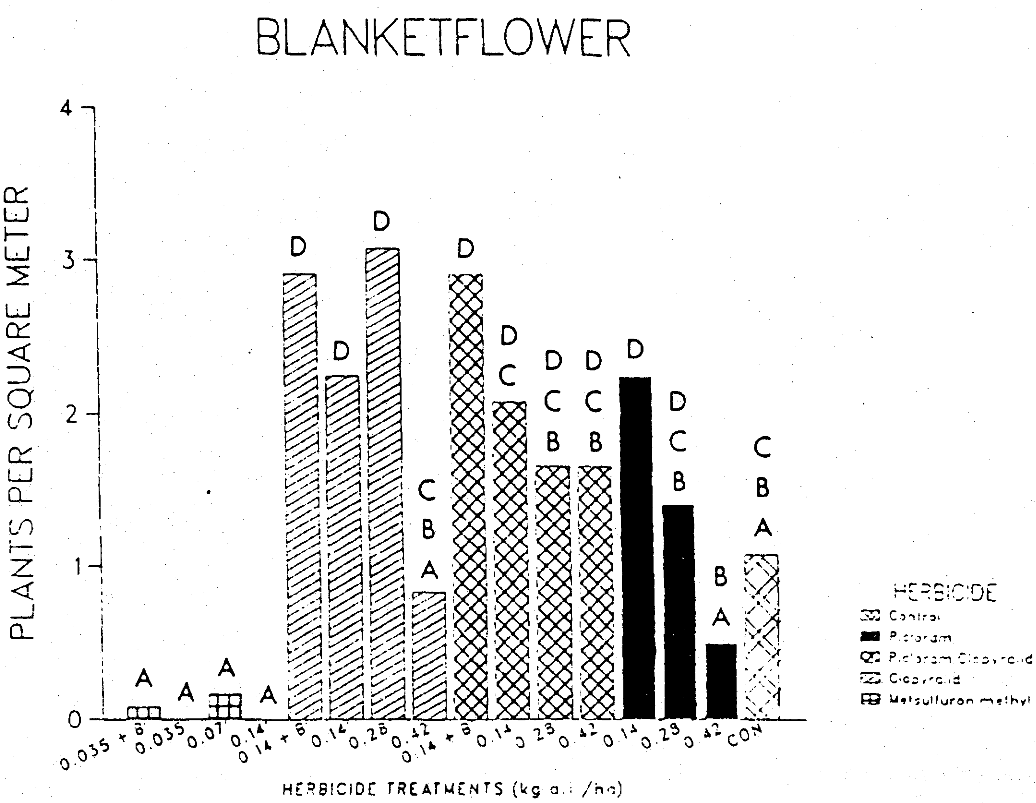

Figure 23. Blanketflower density (plants/m^2), Lolo site, 13 months after treatment.

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[23]Means with the same letter are not significantly different at the 0.10 probability level.

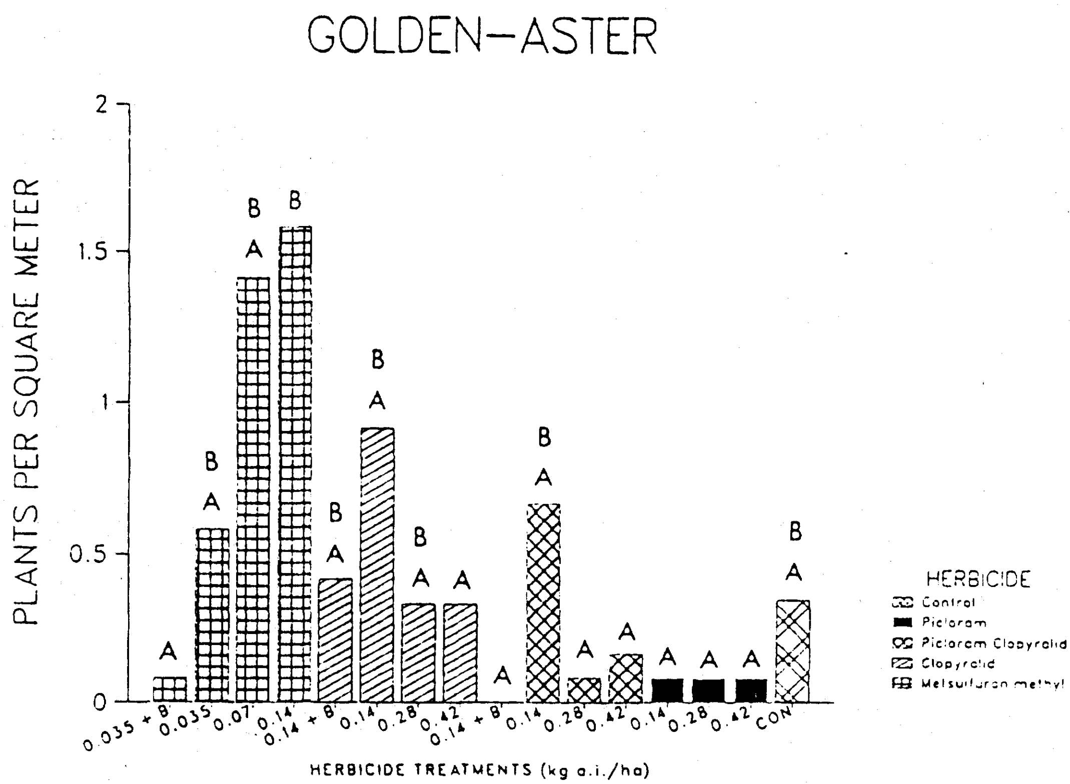

Figure 24. Golden-aster density (plants/m^2), Lolo site, 13 months after treatment.

[24]Means with the same letter are not significantly different at the 0.10 probability level.

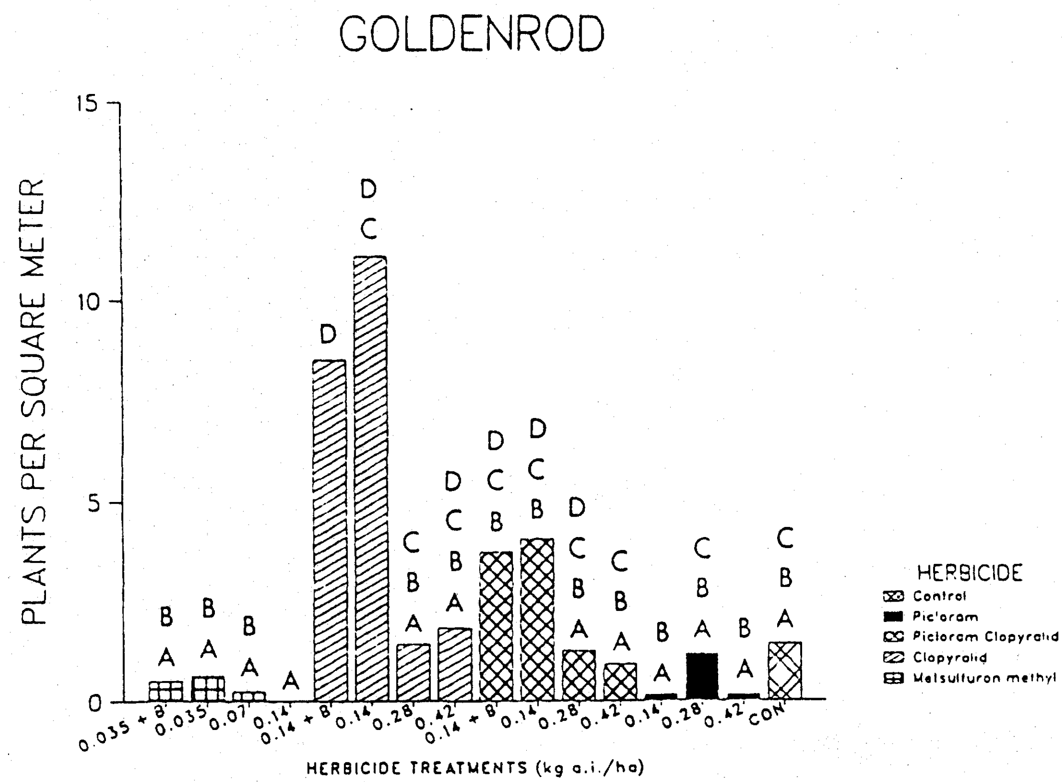

Figure 25. Goldenrod density (plants/m^2), Lolo site, 13 months after treatment.

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[25]Means with the same letter are not significantly different at the 0.10 probability level.

susceptibility to metsulfuron methyl (Warner et al. 1986), while clopyralid (Haagsma, 1975) and picloram (Herbicide handbook) have proven relatively inactive.

Caryophyllaceae

Caryophyllaceae was represented primarily by fescue sandwort (Arenaria capillaris) and thymeleaved sandwort (A. serpyllifolia). These two species reacted similarly to the various treatments, so were analyzed together (Figure 29).

Metsulfuron methyl was extremely active against the sandworts, reducing plant density by 93% to 98 percent. Warner et al. (1986) found that metsulfuron methyl effectively controlled several other species from the Caryophyllaceae, including conical catchfly (Silene spp.), corn cockle (Agrostemma spp.), and cow cockle (Vaccaria spp.).

Picloram applied at 0.14 kg, 0.28 kg, and 0.42 kg reduced plant density by 76%, 95%, and 99%, respectively. Picloram + clopyralid reduced plant density by 41% to 56% on the 0.14 kg rates, jumping to 85% on the 0.28 kg treatments, and 91% on the 0.42 kg treatments. Clopyralid treatments did not reduce sandwort density.

Convolvulaceae

Clover dodder (Cuscuta epithymum) was very common on the Lolo site. This species was not present on any picloram, or the 0.28 kg and 0.42 kg rates of clopyralid + picloram and clopyralid. Very little clover dodder was found on the 0.14 kg treatments of clopyralid + picloram and clopyralid. Metsulfuron methyl did not appear to affect this species, as dense tangles of

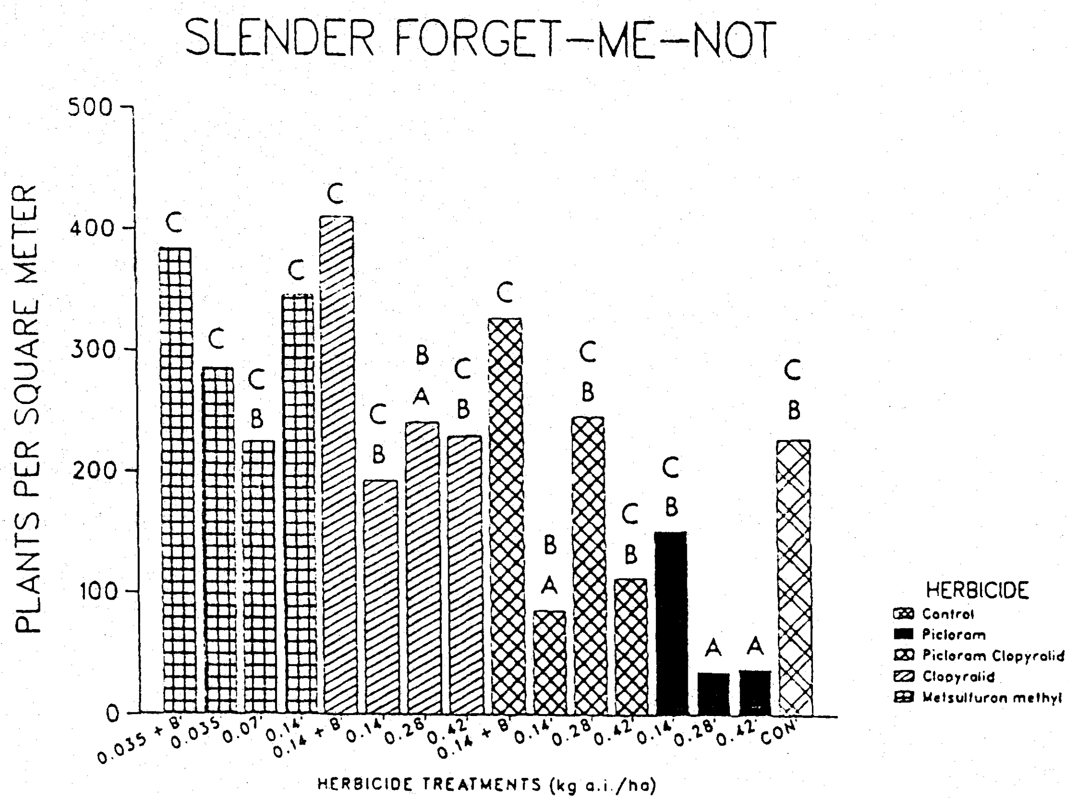

Figure 26. Slender forget-me-not density (plants/m^2), Clearwater site, 13 months after treatment.

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[26] Means with the same letter are not significantly different at the 0.10 probability level.

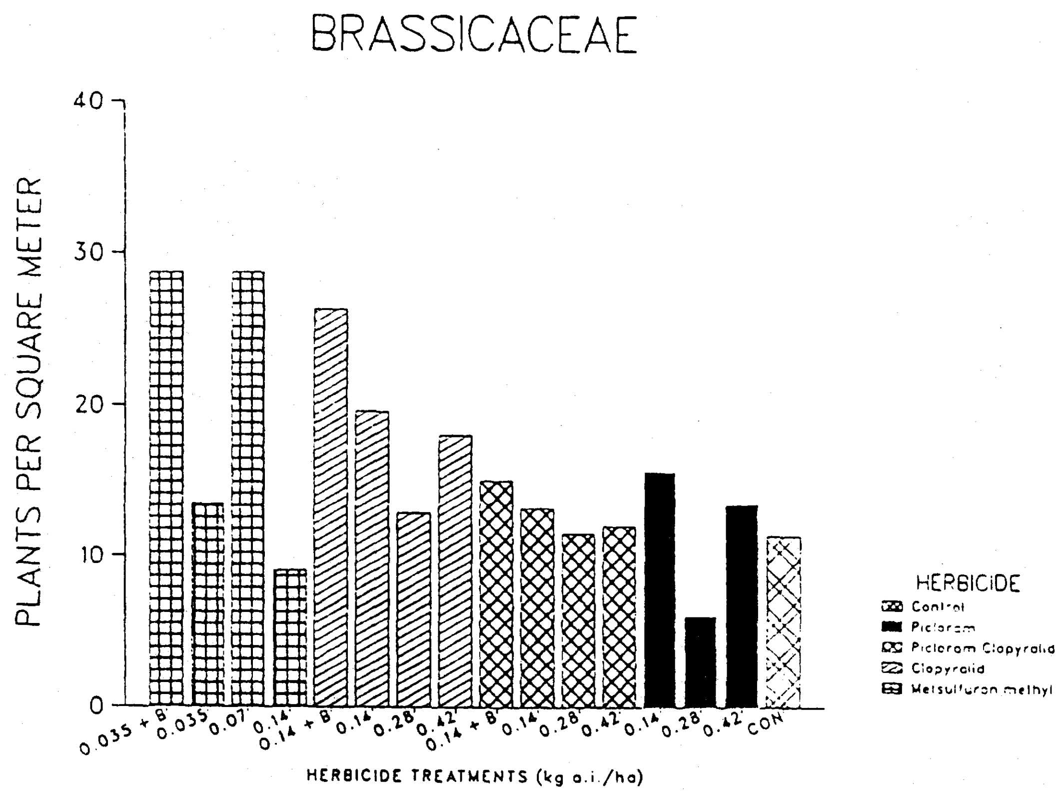

Figure 27. Density (plants/m^2) of all species from the Brassicaceae, Clearwater site, 13 months after treatment.

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[27]Means with the same letter are not significantly different at the 0.10 probability level.

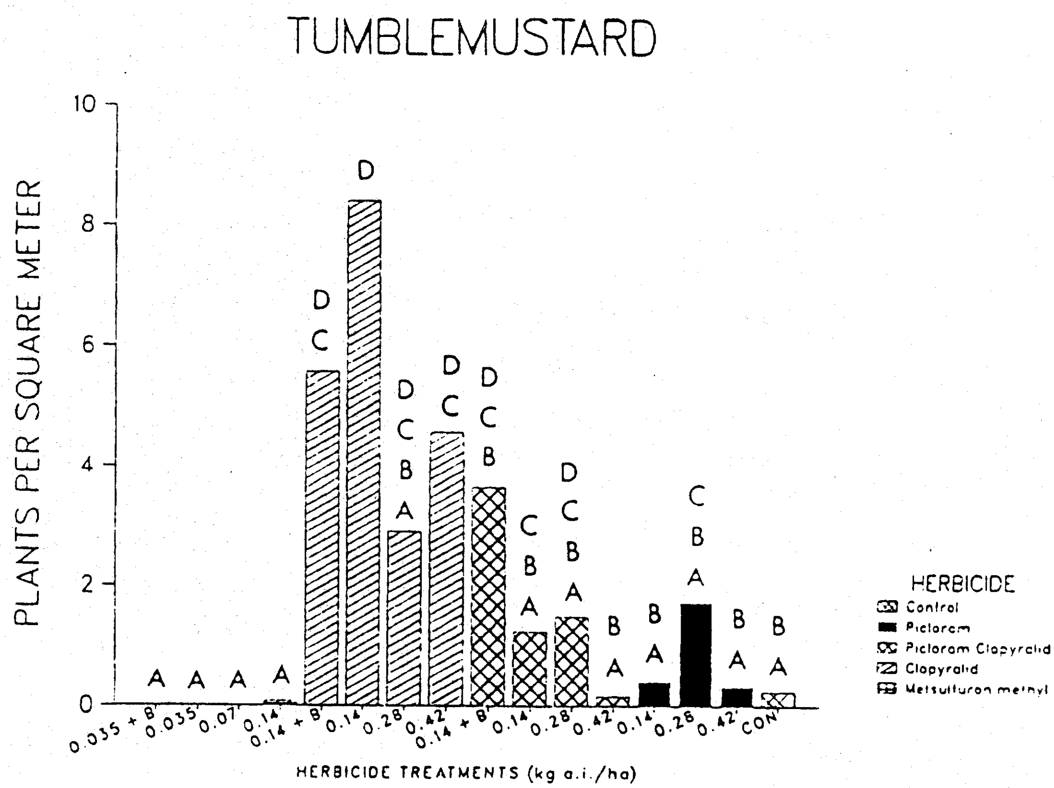

Figure 28. Tumblemustard density (plants/m^2), Clearwater site, 13 months after treatment.

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[28] Means with the same letter are not significantly different at the 0.10 probability level.

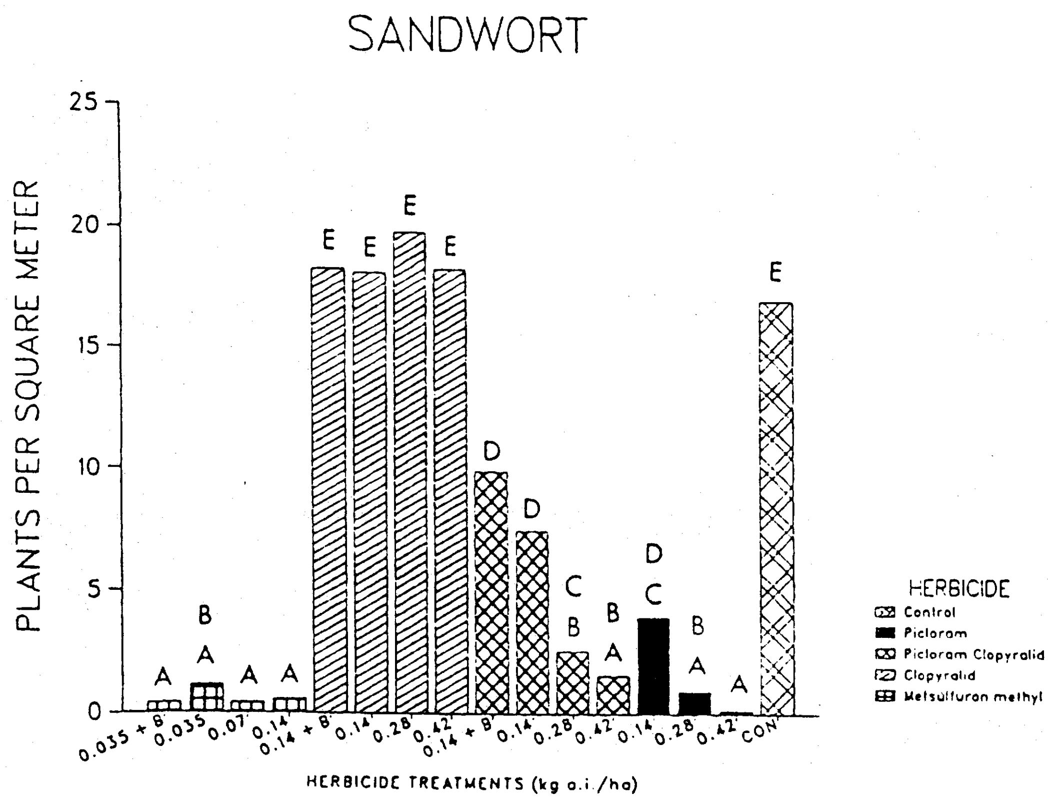

Figure 29. Combined density (plants/m^2) of fescue sandwort and thymeleaved sandwort, Lolo site, 13 months after treatment.

[29] Means with the same letter are not significantly different at the 0.10 probability level.

the vine were found on all metsulfuron methyl plots. Dodder is a selective parasite on spotted knapweed (Chicoine, 1984), so its absence on some treatments may be due to the lack of knapweed rather than herbicide effects.

Field bindweed (<u>Convolvulus arvensis</u>) was relatively uncommon. However, this species did grow on 0.42 kg picloram, 0.42 kg clopyralid, and all metsulfuron methyl treatments, indicating possible resistance to these herbicides. In a previous study, Laning (1963) found that 0.28 kg and 0.54 kg of picloram provided 40% and 88% field bindweed control respectively, 12 months after application.

<u>Fabaceae</u>

Four species from this family were found on the various sites. These species were silky lupine, velvet lupine (<u>Lupinus leucophylla</u>), alfalfa (<u>Medicago sativa</u>), and weedy milk-vetch (<u>Astragalus miser</u>). Silky lupine was the only species common enough to analyze statistically.

Lupine density did not differ from the control on any treatments (Figure 30). Lupine top growth was killed by metsulfuron methyl shortly after spraying, but 13 months later lupine plants were common and vigorous on these plots.

Clopyralid is considered to be highly effective against members of the Fabaceae (Haagsma, 1975). In this study, however, lupine was not killed by clopyralid, and large, healthy, alfalfa and weedy milk-vetch plants were found on several clopyralid treatments. These results indicate that while some species of the Fabaceae, for example honey mesquite (Bovey and Mayeux, 1980;

Jacoby et. al, 1981), are susceptible to clopyralid, several other genera and/or species may be resistant.

Hypericaceae

Common St. John's-wort (Hypericum perforatum) was observed on all clopyralid treatments, and one 0.14 kg picloram treatment. Plants on clopyralid treatments were vigorous, and appeared to have greatly increased growth in response to knapweed removal, with no apparent suppression by clopyralid.

Liliaceae

Meadow death camas (Zigadenus venenosus) does not seem to be susceptible to any of the herbicides, based on its presence on all treatments 13 months after spraying. Yellow bells (Fritillaria pudica) were present in large numbers on all treatments containing picloram or clopyralid, but not on any metsulfuron methyl treatments, suggesting that the latter herbicide kills this species.

Polemoniaceae

Narrow leaved collomia (Collomia linearis) and Microsteris gracilis were present on the Clearwater site, and M. gracilis was present on the Threemile and Lolo sites. All herbicides greatly reduced M. gracilis density at Clearwater (Figure 31). On the Lolo and Threemile sites (Figures 32-33), picloram and picloram + clopyralid treatments significantly reduced plant density, with 0.28 kg and 0.42 kg rates of picloram eliminating this species. In contrast to findings from Clearwater, however, metsulfuron methyl and clopyralid were much less effective against M. gracilis than the other herbicides.

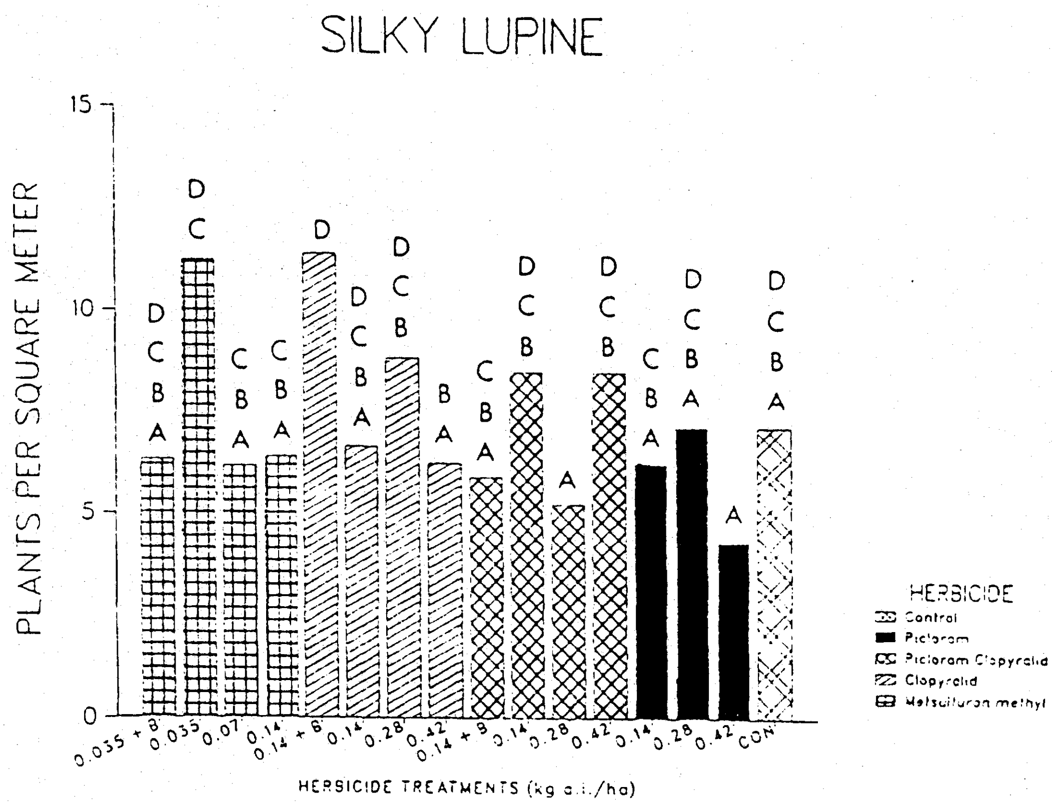

Figure 30. Silky lupine density (plants/m^2), Clearwater site, 13 months after treatment.

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[30] Means with the same letter are not significantly different at the 0.10 probability level.

Polygonaceae

Species from this family included sulfur eriogonum (*Eriogonum umbellatum*), Douglas knotweed (*Polygonum douglasii*), and sheep sorrel (*Rumex acetocella*). Douglas knotweed increased on all burned plots, and was not reduced by any of the herbicides (Figure 34). In contrast, Keys (1975) found that picloram + 2,4-D at 0.035 + 0.14 kg per acre, and clopyralid at 0.07 kg and 0.105 kg/ha controlled wild buckwheat. Pennsylvania smartweed (*P. pennsylvanicum*) and ladysthumb (*P. persicaria*) have also shown susceptibility to clopyralid (Haagsma, 1975). Similarly, prostrate knotweed (*P. aviculare*) was controlled by 0.0042 kg/ha of metsulfuron methyl (Warner et. al, 1986).

Picloram was the only herbicide to reduce sulfur eriogonum density, which declined by 84% on the 0.14 kg rate, 87% on the 0.28 kg rate, and 100% on the 0.42 kg rate (Figure 35).

Sheep sorrel was not found on plots sprayed with 0.42 kg of picloram, or any of the metsulfuron methyl treatments (Figure 36). Large numbers were found on plots treated with clopyralid at 0.28 kg and 0.42 kg. Although no differences were significant, this species appears to be susceptible to picloram and metsulfuron methyl, but not clopyralid. Picloram was previously shown to be effective against curly dock (*R. crispus*) (Laning, 1963).

Primulaceae

Shooting stars (*Dodecatheon* spp.) were observed at the Clearwater site on all picloram, picloram + clopyralid, and clopyralid treatments, as well as the control plots. No plants

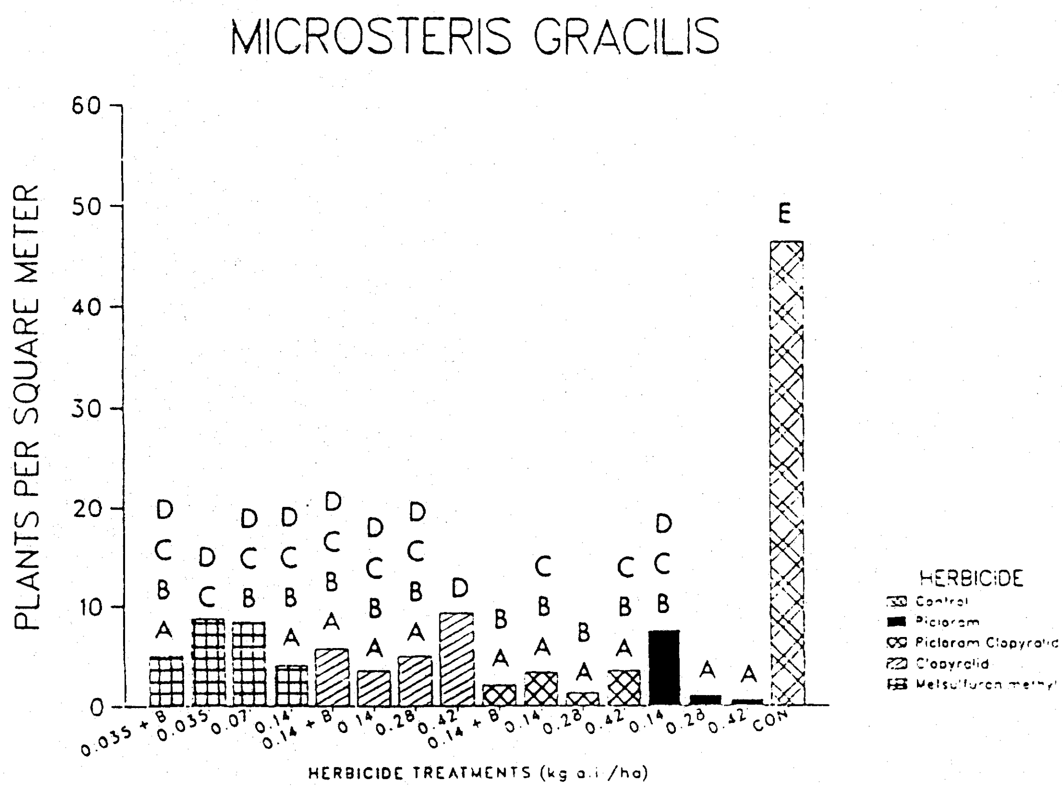

Figure 31. Microsteris gracilis density (plants/m^2), Clearwater site, 13 months after treatment.

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[31] Means with the same letter are not significantly different at the 0.10 probability level.

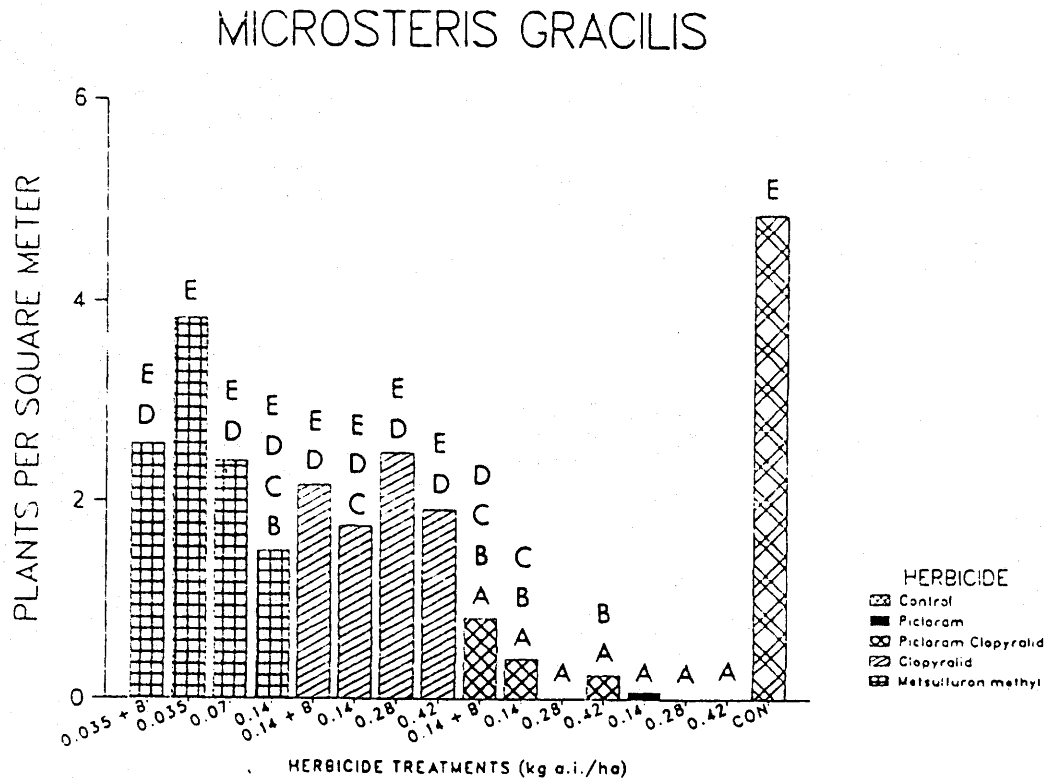

Figure 32. Microsteris gracilis density (plants/m^2), Lolo site, 13 months after treatment.

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[32]Means with the same letter are not significantly different at the 0.10 probability level.

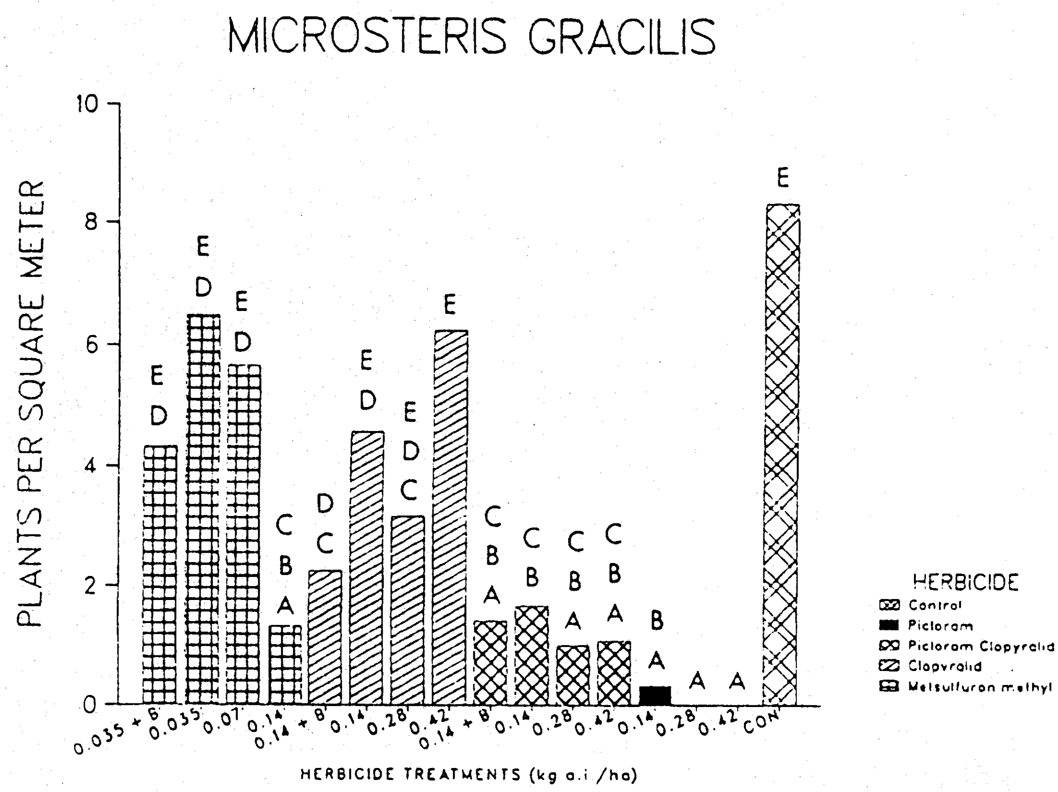

Figure 33. <u>Microsteris gracilis</u> density (plants/m^2), Threemile site, 13 months after treatment.

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[33]Means with the same letter are not significantly different at the 0.10 probability level.

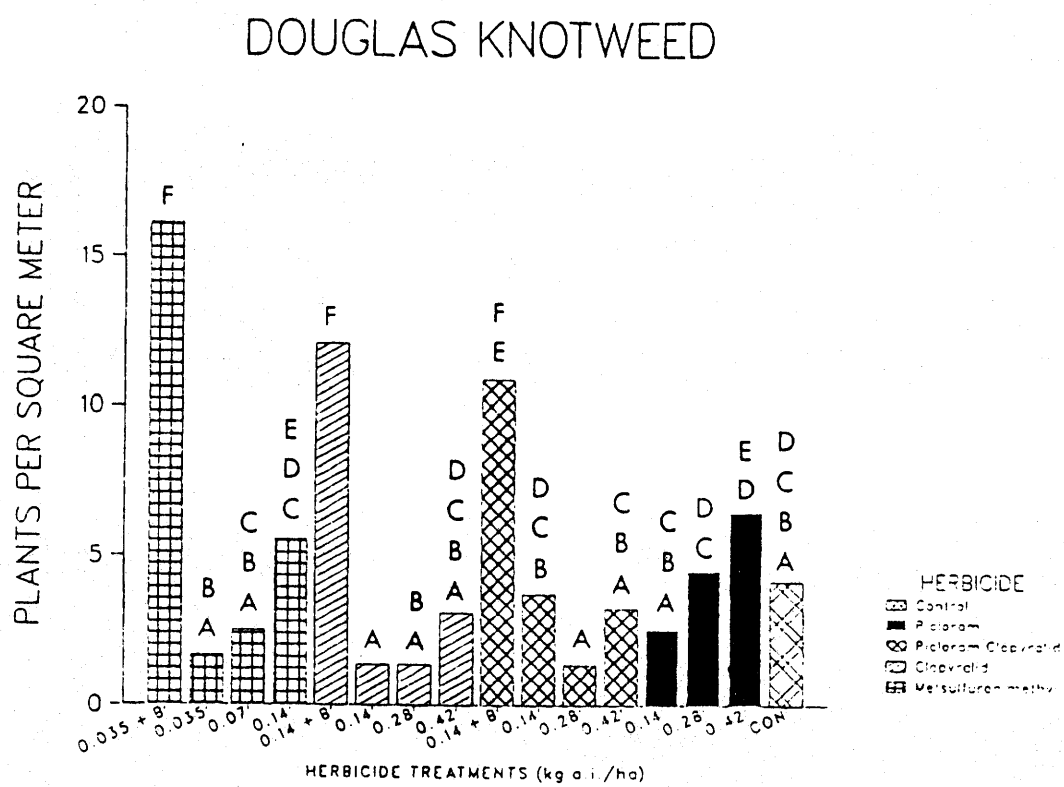

Figure 34. Douglas knotweed density (plants/m^2), Clearwater site, 13 months after treatment.

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[34] Means with the same letter are not significantly different at the 0.10 probability level.

of this genus were found on any metsulfuron methyl treatments, suggesting that shooting stars are killed by metsulfuron methyl.

Rosaceae

Northwest cinquefoil and gland cinquefoil (*Potentilla glandulosa*) were highly sensitive to picloram, picloram + clopyralid, and metsulfuron methyl (Figure 37). These herbicides initially killed all cinquefoil plants. No plants were found on picloram treatments one year after spraying, and only seedlings were present on metsulfuron methyl and picloram + clopyralid plots. Clopyralid treatments did not reduce cinquefoil density, and the plants remained vigorous.

These results are reflected by northwest cinquefoil standing crop data from Threemile (Figure 38). Cinquefoil showed little or no growth on picloram, picloram + clopyralid, and metsulfuron methyl treatments, while production on clopyralid treatments averaged 1600% more than the control.

Scrophulariaceae

Small-flowered blue-eyed mary (*Collinsia parviflora*), wooley mullein (*Verbascum thapsus*), common speedwell (*Veronica arvensis*), butter and eggs (*Linaria vulgaris*), and stiff yellow Indian paintbrush (*Castilleja lutescens*) were present on one or more sites. As a group, these species were reduced by only one treatment, that being the 0.14 kg rate of metsulfuron methyl (Figure 39).

Small-flowered blue-eyed mary was reduced by all rates of metsulfuron methyl (Figure 40). No other herbicides reduced blue-eyed mary density.

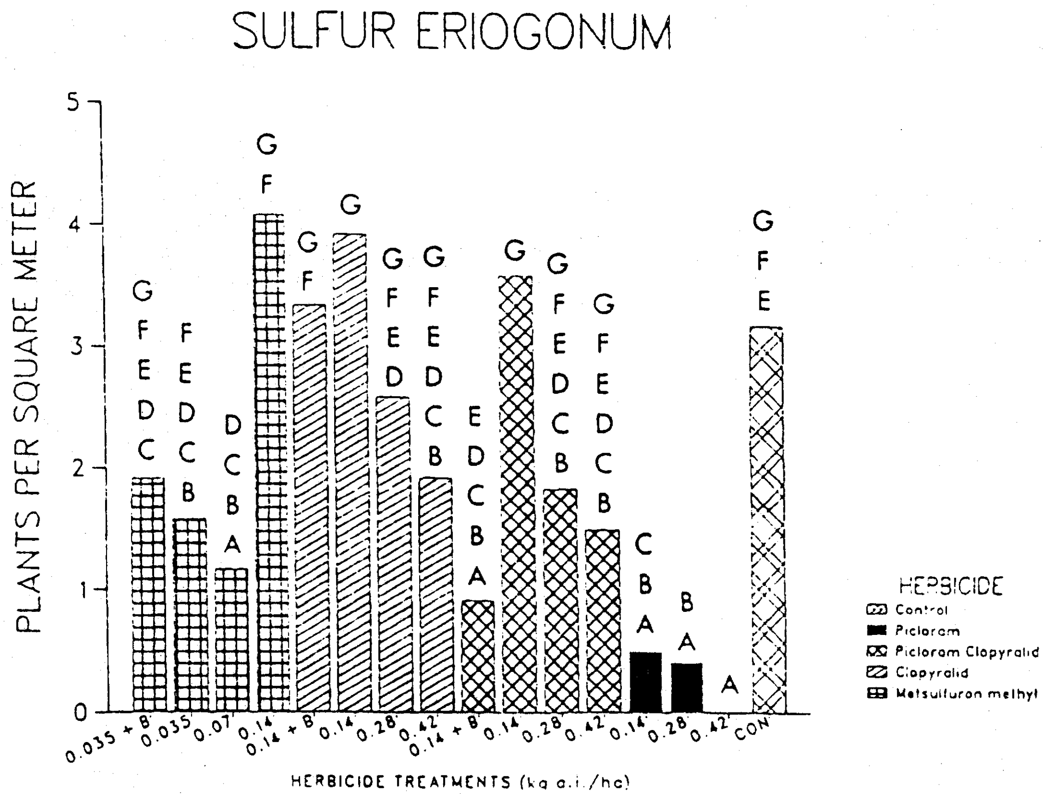

Figure 35. Sulfur eriogonum density (plants/m^2), Clearwater site, 13 months after treatment.

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[35]Means with the same letter are not significantly different at the 0.10 probability level.

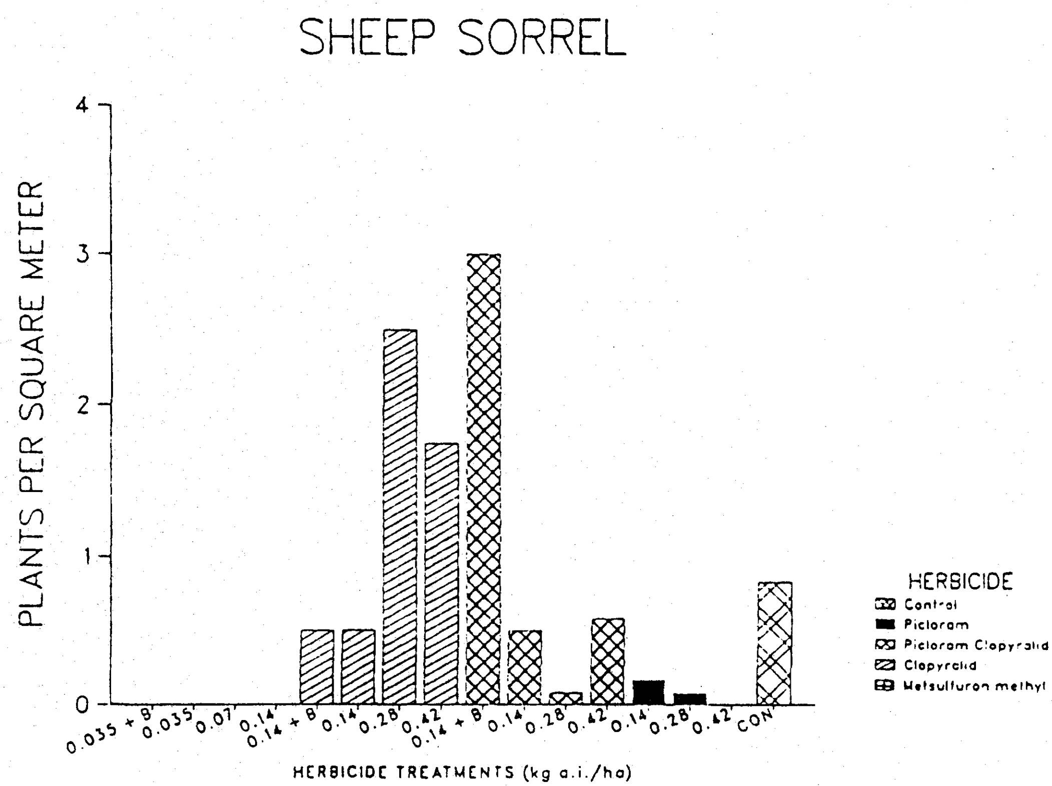

Figure 36. Sheep sorrel density (plants/m^2), Threemile site, 13 months after treatment.

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[36]Means with the same letter are not significantly different at the 0.10 probability level.

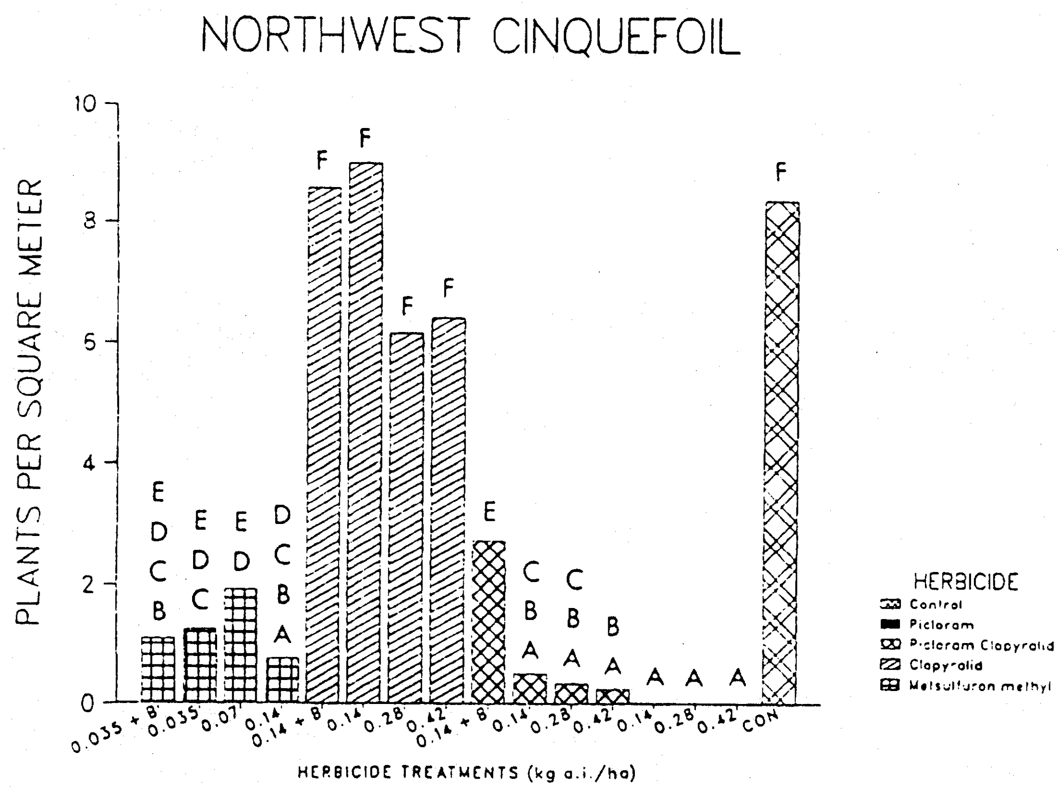

Figure 37. Northwest cinquefoil density (plants/m^2), Lolo site, 13 months after treatment.

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[37]Means with the same letter are not significantly different at the 0.10 probability level.

Common speedwell density was not reduced by any of the treatments.

A single patch of butter and eggs was found on the Threemile site, growing on the 0.14 kg picloram treatment. The plants appeared to be growing vigorously, indicating that butter and eggs is not highly susceptible to picloram.

Wooley mullein grew on all plots except the metsulfuron methyl and 0.42 kg picloram treatments, indicating a possible susceptibility to these herbicides.

Herbicide Response - 1987

The responses of each site to the herbicides picloram, clopyralid, and picloram+clopyralid at four levels and no herbicide (check) were estimated using plant density data in 1987. The treatments using metsulfron methyl were not monitored because 1985 and 1986 data showed that metsulfron methyl, at rates applied, was not effective at controlling spotted knapweed and killed many native forbs.

Methods. Forb density in 1987 was measured on June 16-20 at the Clearwater site, during the last week of June on the Lolo Site, and on July 11-12 at the Threemile site. For all plants except balsamroot and stoneseed the density of each species was measured by counting the number of plants within a rectangular 0.5 m^2 plot. For balsamroot and stoneseed we measured density by counting all plants within the treatment plot.

Results. All picloram, clopyralid, and picloram+clopyralid mixes had reduced knapweed numbers compared to the check (Figs. 41, 42,

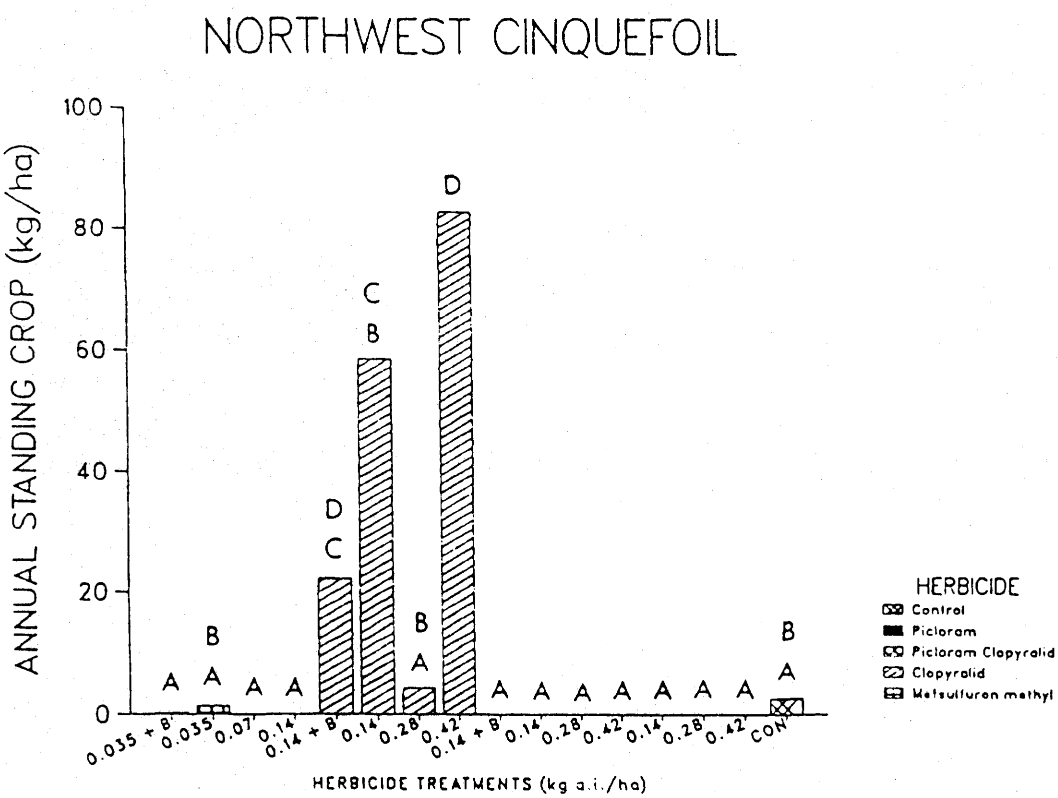

Figure 38. Northwest cinquefoil standing crop (kg/ha), Threemile site, 15 months after treatment.

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[38]Means with the same letter are not significantly different at the 0.10 probability level.

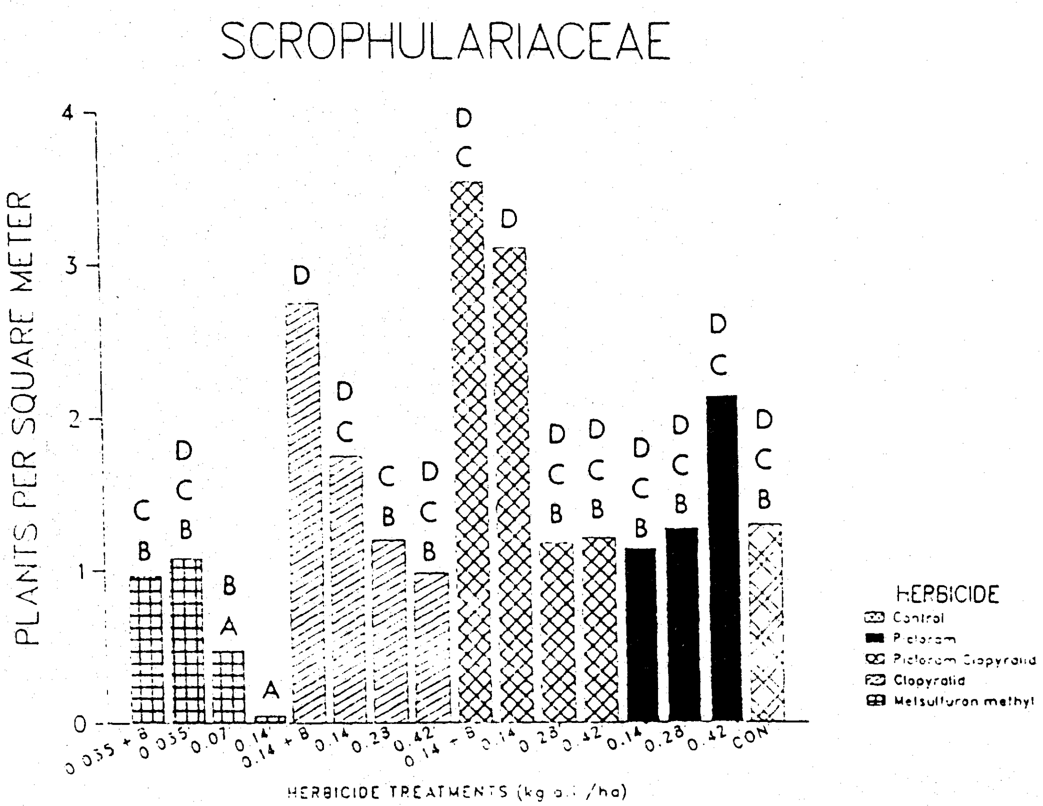

Figure 39. Density (plants/m^2) of all species from the Scrophulariaceae, Threemile site, 13 months after treatment.

[39]Means with the same letter are not significantly different at the 0.10 probability level.

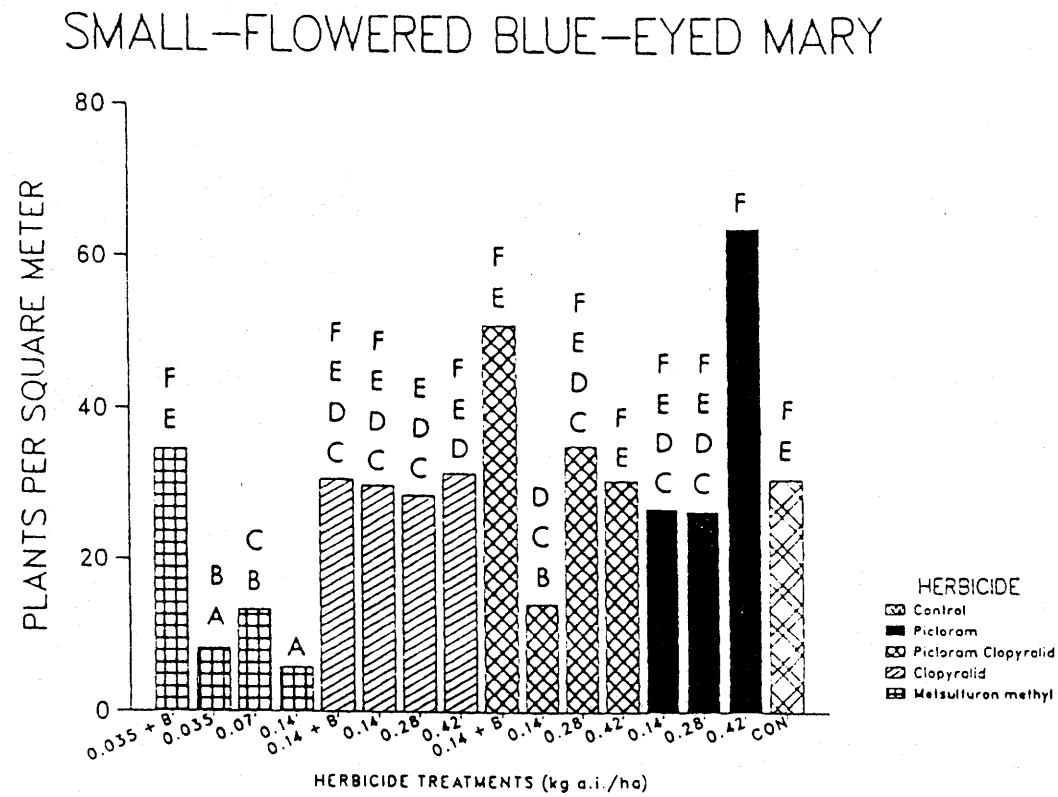

Figure 40. Small-flowered blue-eyed mary density (plants/m^2), Clearwater site, 13 months after treatment.

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[40]Means with the same letter are not significantly different at the 0.10 probability level.

and 43). The 0.42 kg/ha picloram treatment continued to eliminate almost all knapweed plants and we believe this treatment will remain effective for several more years. For all clopyralid treatments knapweed control was becoming ineffective with many knapweed plants producing flowers. The 0.28 picloram treatment and picloram+clopyralid at 0.28 and 0.42 kg/ha continued to be very effective at controlling knapweed. We observed that some knapweed plants flowered on these treatments but we believe these treatments should remain effective for at least three years and possibly much longer. Picloram at 0.14 kg/ha gave variable results. As stated in the 1986 discussion it is very likely that the poor control for this treatment at the Clearwater site was a miscalculation in the herbicide mix. For the Lolo site the 0.14 kg/ha picloram treatment remained very effective at controlling knapweed in 1987 but at the Threemile site spotted knapweed density averaged 35 plants/m^2 and many knapweed plants produced flowers. The application of herbicides for this study occurred during a drought year which probably reduced herbicide effectiveness. We believe that the 0.14 kg/ha picloram treatment may be effective under optimum herbicide timing and application conditions. However, during most years it is apparent that picloram at the 0.14 kg/ha would likely produce variable results and long-term control of knapweed would certainly be decreased.

Although we did not measure grass production in 1987 it would be our hypothesis that grass production was greater on all the clopyralid, picloram+clopyralid, and picloram treatments as

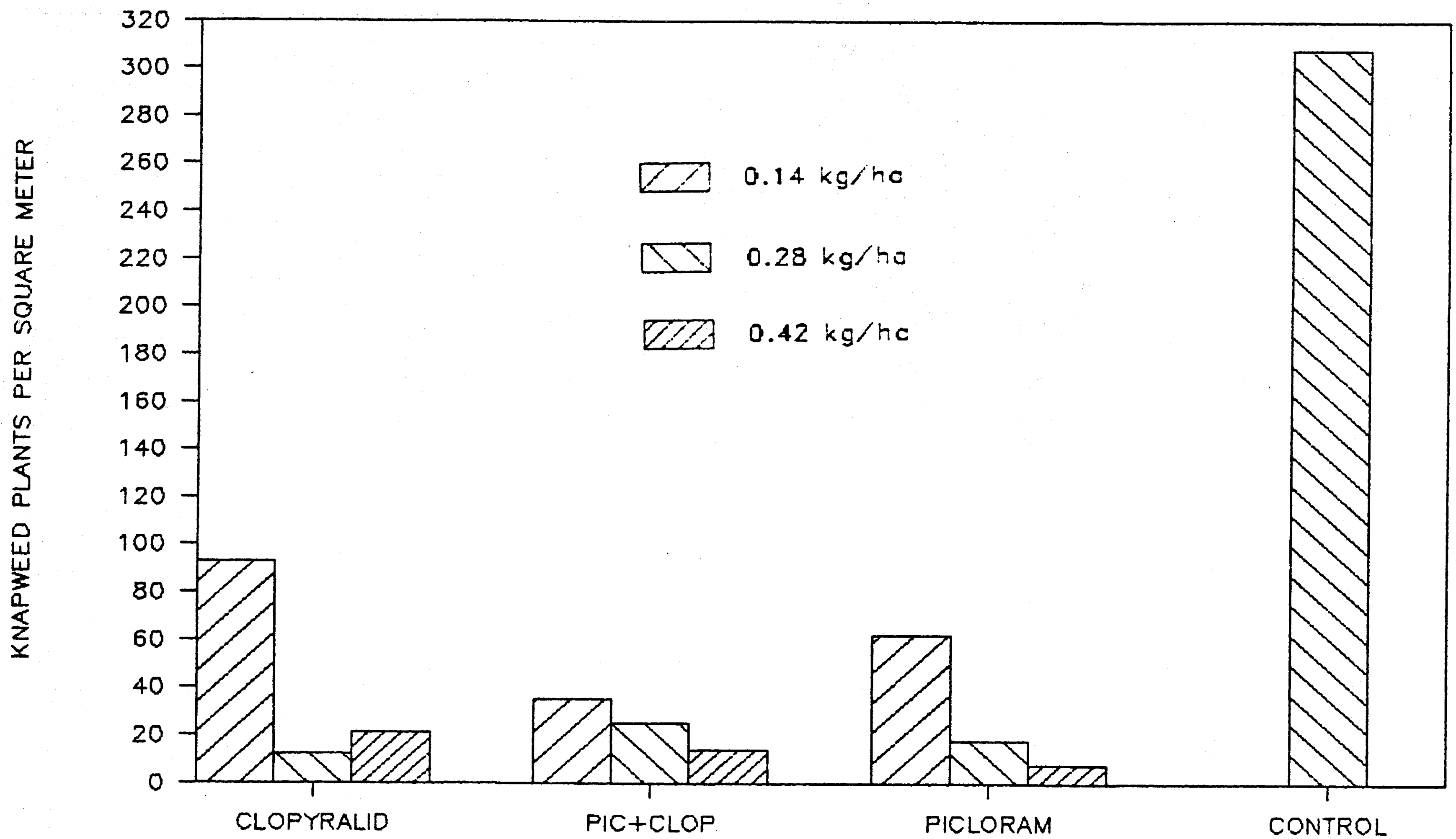

Figure 41. Spotted knapweed density (plants/m^2) Clearwater site, 26 months after treatment.

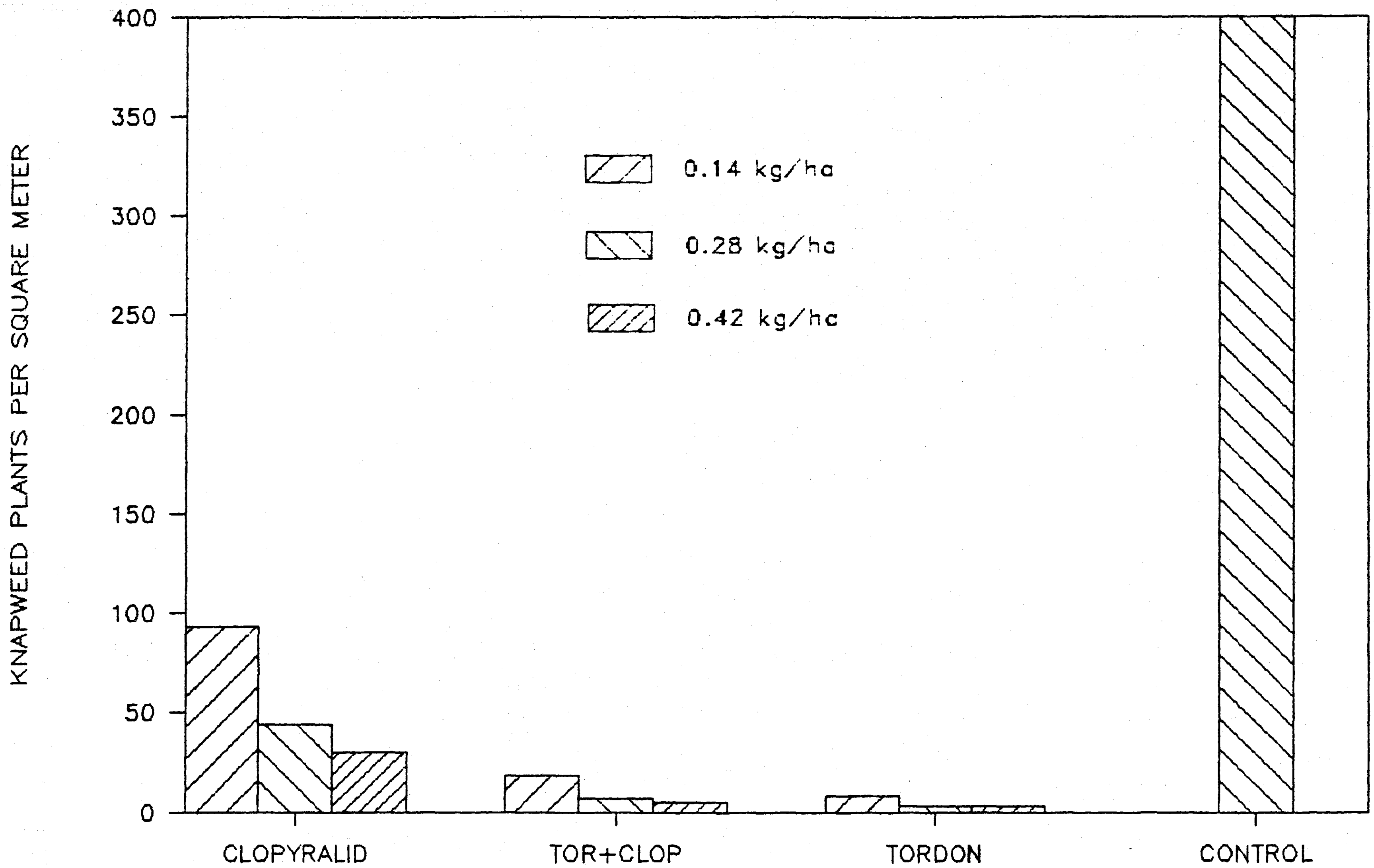

Figure 42. Spotted knapweed density (plants/m^2) Lolo site, 26 months after treatment.

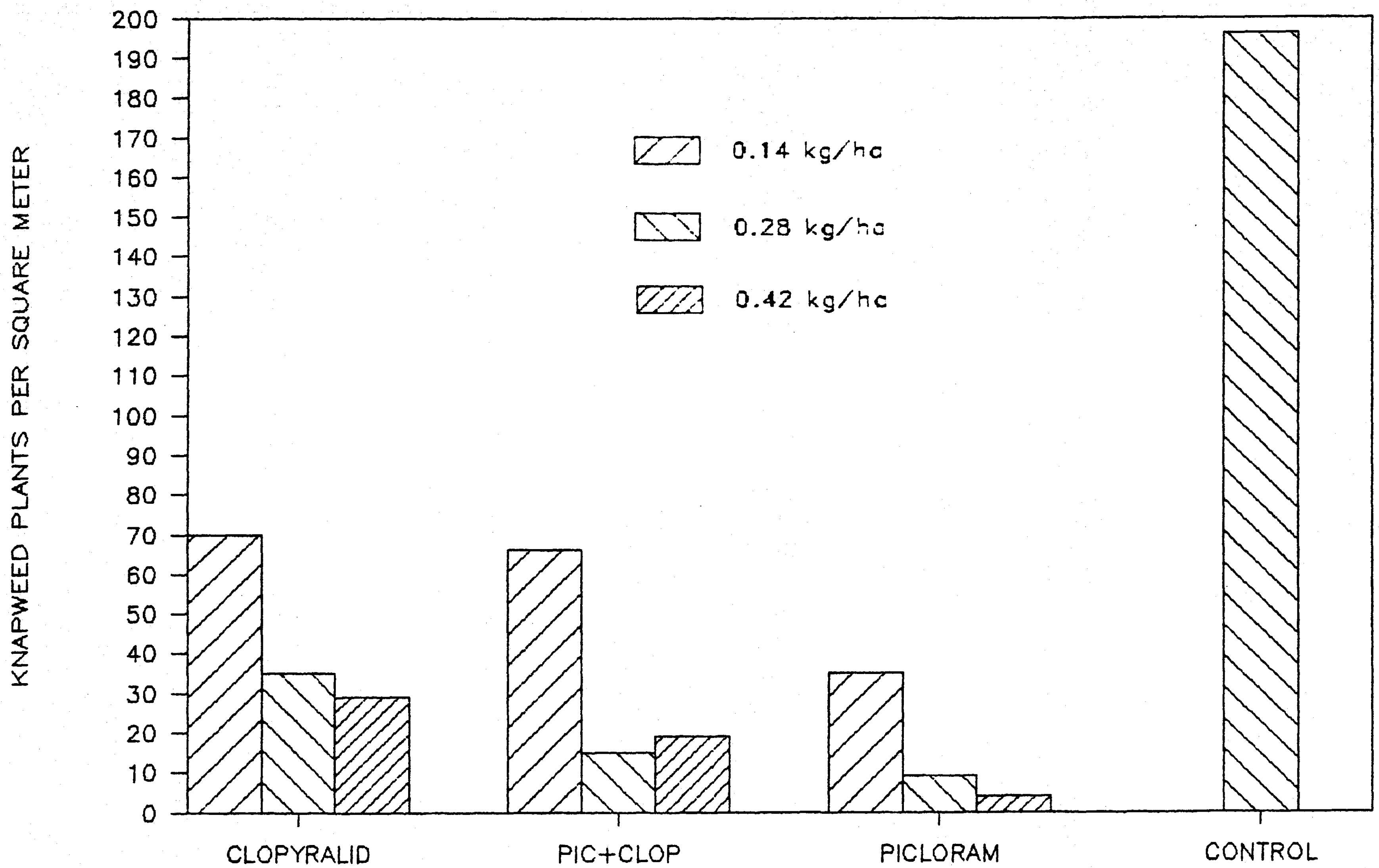

Figure 43. Spotted knapweed density (plants/m^2) Threemile site, 26 months after treatment.

compared to the control. Seed head production of grasses was evidently greater on these treatments as compared to the check. The 1987 forb selectivity results are similar to the 1986 results. In most cases density of native species was not great enough to determine consistent response (Tables 1, 2, and 3). The three major species (groups) having a different response to clopyralid and picloram were silky lupine (Table 3), sulfur eriogonum (Table 1) and herbaceous cinquefoil (*Potentilla gracilis* and *P. glandulosa*) (Table 2). Picloram at the applied rates was more detrimental to these groups than equivalent rates of clopyralid.

Important species reduced by both picloram and clopyralid were western yarrow, *Lomatium* spp. and *Arnica fulgens*. Yarrow was reduced significantly on two of the sites where it occurred at densities greater than one plant/m^2. The lomatiums also appeared to be detrimentally affected by picloram and clopyralid on the Clearwater site. The lomatiums (bisquitroot) have some wildlife value. Arnica is a showy early Asteraceae which may be important for aesthetic reasons. None of the herbicides (or rates) completely eliminated Arnica (or any species) but the reduction was noticeable on most sites. Sites with Arnica or lomatiums could perhaps be sprayed later with clopyralid with less of a detrimental effect since Arnica and several of the lomatiums flower in early June on these sites.

A common perception of many people is that herbicide treatments result in a grass monoculture. For these sites it was apparent that on the checks (no treatment) for the three study

Table 1. Influence of herbicide treatments (kg/ha a.i.) on the density (number/m²) of forb species at the Clearwater Site in June 1987.

		Clopyralid			Picloram			Pic + Clop		
	Control	0.14	0.28	0.42	0.14	0.28	0.42	0.14	0.28	0.42
Yarrow[1]	2.2c[2]	1.4bc	0.7ab	0a	0.3a	0.2a	0a	0.6ab	0.1a	0a
Pussytoes	1.2a	0.6a	2.0a	2.4a	1.6a	0.3a	0.1a	0.6a	0.3a	0.1a
Arnica	11.2c	0.2a	1.4ab	1.8ab	2.6b	0.4a	2.8b	2.8b	3.8b	0a
Rockcress	1.4a	0.6a	0.2a	0.3a	0.8a	0.3a	3.0a	1.4a	0.4a	3.2a
Fleabane	0.1a	0a	0a	0a	0a	0a	0a	0a	0a	0a
Eriogonum	1.2ab	0.6bc	1.8a	0.8bc	0.8bc	0.1a	0.1c	0.6bc	1.4ab	0.2c
Golden-aster	0a	0a	0a	0a	0.1a	0.6a	0.1a	0.3a	0a	0a
Hawkweed	0.2a	0.2a	0a	0a	0.1a	0a	0.1a	0a	0a	0a
Bisquitroot	0a	0a	0a	0a	0.4a	0.2a	0.1a	0.6a	0.2a	0a
Lomatium	2.0b	1.8b	0.2a	0.4a	0.2a	0.2a	0a	1.4b	0.3a	0.2a
Lupine	3.6ab	2.0bc	1.8bc	0.8c	1.9bc	2.4bc	2.1bc	3.4ab	2.8ab	3.8a
Microsteris	0.6a	1.0a	0.2a	0.3a	1.6a	1.2a	2.0a	1.4a	2.4a	1.2a
Cinquefoil	0.1a	2.0a	1.4a	0.1a	0.3a	0a	0.1a	0a	0.6a	0.3a
Death Camas	0a	0a	0a	0a	0.3a	0.3a	0a	0.1a	0a	0a

[1] Scientific names are listed in Appendix 1.
[2] Means followed by a similar letter in the same row are not different at the 0.05 level of probability.

Table 2. Influence of herbicide treatments on the density (number/m^2) of forbs by species at the Lolo Site in June 1987.

		Clopyralid			Picloram			Pic + Clop		
	Control	0.14	0.28	0.42	0.14	0.28	0.42	0.14	0.28	0.42
Yarrow[1]	2.4c[2]	4.8d	1.8c	0.1a	0.3a	0.6a	0.1a	0.8b	0.4a	0.1a
Agoseris	0a	1.5b	2.2b	1.0ab	0.1a	0.4a	0a	0.7a	0.5a	0.1a
Pussytoes	0.2a	0a	0.1a	0.1a	0a	0a	0a	0.1a	0a	0a
Sandwort	0.1a	0.9a	0.1a	0.1a	0.3a	0.1a	0a	0.1a	0.8a	0.1a
Arnica	1.5b	1.1b	0.1a	0a	0.1a	0.1a	0.1a	1.8b	0a	0a
Arabis	0a	0.1a	0.1a	0a	0a	0a	0a	0.1a	0a	0.1a
Milk Vetch	0.6a	0a	0a	0.3a	0.1a	1.0a	0.1a	1.4a	0.2a	0
Balsamroot	0.5bc	0.3ab	0.2ab	0.1a	0.9c	0.3ab	0a	0.3ab	0.4ab	0.1a
Bindweed	0a	0a	0.1a	0.3a	0a	0.6a	0.6a	0.8a	0.2a	0.4a
Toadflax	0.2a	0.7a	0.4a	0.9	0.4a	0.6a	0.1a	0.6a	0.1a	0.2
Dodder	0.7c	0.5bc	0a	0.3b	0.1a	0a	0a	0a	0a	0a
Fleabane	0.3a	1.1ab	0a	0a	0.1a	2.0ab	3.2ab	2.4ab	0.2a	0.4a
Yellowbell	0a	0a	0a	0.1	0a	0.1a	0a	0.1a	0.2a	0.1a
Blanketflower	0a	0.7a	1.3a	0.2a	0.3a	0.9a	0.2a	0.8a	0.2a	0.4a
Goldenaster	0.1a	0.2a	0.1a	0a	0a	0a	0a	0.2a	0a	0a
Gromwell	0a	0.1a	0.1a	0.6a	0.2a	0.5a	0a	0.1a	0.1a	0.1a
Lomatium	0.2a	0a	0.1a	0a	0a	0a	0a	0.1a	0a	0a
Lupine	1.0bc	1.8a	1.1bc	0.6ab	1.5a	0.3a	0.4a	1.4c	1.0bc	0.1a
Cinquefoil	7.8d	5.8cd	4.4bc	3.0b	0.2a	0.1a	0.1a	0.6a	0.5a	0.2a
Rose	0a	0.1a	0a	0a	0a	0.2a	0a	0a	0.1a	0.5a
Dandelion	0.4a	0.1a	0.1a	0.1a	0a	0a	0.2a	0.1a	0a	0.1a
Salsify	0.1a	0.6a	0.2a	0.1a	0.6a	0.1a	0a	0.1a	0a	0a
Death Camas	0.6a	0a	0.1a	0.2a	0.1a	0.5a	0.8a	0.5a	0.1a	0.5a

[1] Scientific names are listed in Appendix 1.
[2] Means followed by a similar letter in the same row are not differnt at the 0.05 level of probability.

Table 3. Influence of herbicide treatments on the density (number/m^2) of forbs by species at the Threemile Site in June 1987.

		Clopyralid			Picloram			Pic + Clop		
	Control	0.14	0.28	0.42	0.14	0.28	0.42	0.14	0.28	0.42
Yarrow[1]	0.1a[2]	0.2a	0.1a	0.1a	0.1a	0a	0a	1.2a	0.1a	0a
Fleabane	0a	0.1a	0.3a	0.8a	0a	0a	0.1a	0.1a	0a	0a
Rockcress	0.1a	0a	0a	0a	0.2a	0a	0a	0a	0a	0.1a
Goldenaster	0a	0a	0.1a	0a	0a	0.1a	0a	0.1a	0a	0a
Velvet Lupine	0.1a	0a	0.1a	0.1a	0.3a	0.1a	0a	0a	0.1a	0a
Silky Lupine	0a	3.4bc	0.3a	3.6bc	2.2b	0.3a	0a	2.2a	4.1c	0.2a
Cinquefoil	0.6a	0.4a	0.5a	3.6b	0a	0a	0a	0a	0a	0a
Rose	0a	0a	0.2a	0.2a	0a	0a	0.1a	0a	0a	0a
Sheep Sorrel	0a	0.3a	6.6b	8.8b	0a	0.6a	0a	0.1a	0.9a	1.4a
Mullen	0a	0.1a	0.3a	0a	0.1a	0a	0a	0.8a	0a	0a

[1]Scientific names are listed in Appendix 1.
[2]Means followed by a similar letter in the same row are not different at the 0.05 level of probability.

sites knapweed was having a large impact on native forbs. Our study site on the Threemile site was an area that had been a homestead and possibly plowed. Native grasses were infrequent and no native perennial forb occurred at greater than 0.6 plants/m^2 for the check (Table 3). Knapweed density averaged 196 plants/m^2 for the check which gave the site the appearance of a knapweed monoclimax. Perennial native forbs on check plots were more frequent at the Lolo site and Clearwater site, although knapweed remained the dominant forb. For the Clearwater site Arnica was the dominant native forb, averaging 11.2 plants/m^2 compared to 308 knapweed plants/m^2. No native forb occurred at greater than 3 plants/m^2 at the Lolo site compared to 400 knapweed plants/m^2. It seems apparent that the introduction of knapweed at the densities found on these sites will reduce the potential of all native plants to reproduce and to reestablish on these sites. For native grasses seed head production was visibly greater where knapweed was controlled. This increase in seedhead production can be attributed to an increase in plant vigor of the grasses because of less competition with knapweed.

Managers of public lands have the responsibility to maintain these lands in their most productive capacity. For many sites the maintenance of the "natural plant community" should be a priority so that future generations will be able to enjoy these areas. It is doubtful that knapweed sites are the most productive for livestock or wild ungulates. More information is needed on the impact of spotted knapweed and herbicides on native forbs. However, for any site where the native community still

exists and knapweed has not invaded (and the site has the potential of becoming knapweed dominated) the control of knapweed is strongly suggested. For most areas this control would include herbicide application to any nearby sites with knapweed that may result in invasion of the "natural" area. We believe this type of action is warranted because of the impact of spotted knapweed on all native plants. For sites with a large component of knapweed and a remnant native plant component it may be desirable to control knapweed to maintain the appearance of a native prairie with a diverse native grass component. The herbicides that are known to be very effective at controlling knapweed may kill other forbs but the same fate may exist for these forbs in the knapweed dominated community.

Conclusions and Management Implications

Of the herbicides used in this study, 0.42 kg/ha of picloram provided the best spotted knapweed control. This was due to the effective residual activity obtained, which completely eliminated spotted knapweed through 15 months. Picloram applied at 0.28 kg, and picloram + clopyralid at 0.28kg and 0.42 kg were nearly as effective, but allowed some reinvasion by knapweed seedlings on at least one site. Considerable knapweed seedling growth occurred on plots treated with 0.14 kg, 0.28 kg, or 0.42 kg of clopyralid; 0.14 kg of picloram; or 0.14 kg picloram + clopyralid.

Metsulfuron methyl did not reduce spotted knapweed at the applied rates, although it did stunt knapweed growth. Spotted knapweed flowered on all metsulfuron methyl treatments 13 months after treatment, so this herbicide was considered ineffective for spotted knapweed control at the applied rates.

Knapweed control varied considerably among the three sites. The herbicides were generally most effective on the Lolo site. The Clearwater and Threemile sites had more reinfestation, possibly because cattle grazing after spraying led to further site disturbance.

All spotted knapweed plants were seedlings or rosettes on plots sprayed with 0.28 kg and 0.42 kg of clopyralid and all rates of picloram or picloram + clopyralid. Plots sprayed with these treatments should not need to be resprayed until at least the second year after the initial treatment. Clopyralid provided the least residual control, so two years may be the maximum allowable interval between spraying if seed production by knapweed is to be eliminated. Respraying every two years may also be needed for 0.14 kg rates of picloram and picloram + clopyralid, because of the knapweed seeding reinvasion. The 0.28 kg and 0.42 kg rates of picloram and picloram + clopyralid allowed little, if any, reinfestation, so respraying should not be necessary until at least three years after the initial treatment. On sites that are grazed, or otherwise disturbed, the period of herbicide effectiveness will probably be reduced.

Burning did not improve spotted knapweed control. Results were considered inconclusive, however, because the dry conditions

following burning were not favorable for knapweed seed germination. If no significant increase in knapweed seed germination occurred prior to spraying, then knapweed's seed reserve in the soil would have remained intact. Additional study is needed to determine whether burning or some other method can be used to reduce knapweed's ability to reinfest a treated site.

Total grass standing crop was increased on most plots where knapweed was initially controlled. The greatest increase was 375% (1670 kg/ha) at Clearwater 15 months after treatment. These increases occurred despite the drought of 1985, and the cattle grazing at Threemile and Clearwater during 1985.

Kentucky bluegrass, Canada bluegrass, and prairie junegrass seemed to increase growth more readily than species such as rough fescue, bluebunch wheatgrass, and Idaho fescue. However, all of these species were observed to increase in size and vigor on plots where knapweed was initially controlled.

The increased grass production following knapweed removal is a major consideration for management. Increased grass standing crop allows increased grazing by livestock and wildlife within a year or two after spraying. This provides a relatively fast return on investment compared to most other control methods. Biological control, for example, can require many years to have a significant effect on knapweed growth, and will not eliminate the weed from a site. Therefore, forage production will not increase for several years, and will probably never increase as dramatically as forage increases following herbicide spraying.

In terms of selectivity, clopyralid caused the least damage

to non-target species. Picloram + clopyralid was of intermediate selectivity. Picloram and metsulfuron methyl were the least selective.

Clopyralid led to reduction in several species from the Asteraceae, including western yarrow, rose pussytoes, and arnica, as well as nineleaf lomatium and Microsteris gracilis. Species from the Asteraceae that showed resistance to clopyralid included arrowleaf balsamroot, field fluffweed, blanketflower, and golden-aster. In addition, species from the Brassicaceae, Caryophyllaceae, Fabaceae, Liliaceae, Polygonaceae, Rosaceae, and Scrophulariaceae showed little susceptibility to this herbicide.

Metsulfuron methyl, picloram, and picloram + clopyralid reduced all species that were reduced by clopyralid, as well as several additional species. These additional species were: 1) picloram + clopyralid reduced density of northwest cinquefoil (Rosaceae) and two species of sandwort (Caryophyllaceae), 2) picloram reduced northwest cinquefoil, the sandworts, sheep sorrel (Polygonaceae), and field fluffweed, 3) metsulfuron methyl reduced northwest cinquefoil, the sandworts, sheep sorrel, blanketflower and possibly yellow bells (Liliaceae).

The high selectivity shown by clopyralid is desirable from an ecological standpoint, but there is one obvious disadvantage. If other noxious weeds are present, they may survive and cause additional weed problems. For this reason, all weeds on a site should be identified before deciding which herbicide(s) to apply to a specific site.

The maintenance of elk winter range is critical. Elk winter

ranges are declining in acreage and productivity in much of Montana. Although there is little direct information on the influence of knapweed invasion on the quality of elk winter range we can hypothesize on some of the effects of knapweed invasion on elk winter range. Forage preference studies of elk during the winter and spring indicate that elk have a strong preference for grass (Murie 1951; Gaffney 1941; Smith 1930; Knight 1970; Stevens 1966; Mackie 1970; Morris and Schwartz 1957; Snyder 1969). In many of these forage preference studies elk diets were over 85% grasses during the critical winter and early spring season. Our herbicide plots were on three sites that would be considered elk winter range. On all these sites knapweed invasion has greatly decreased grass production. For untreated areas total grass production averaged 522 lb/ac compared to 1602 lb/ac for the 0.42 kg/ha picloram treatment two growing seasons post-treatment. Not all grass standing crop would be available to the elk, nor would all be preferred by elk. Using a 50% value for usable forage and a conservative value of 20 lbs./day/dry matter consumption by elk our untreated areas could support 13 elk days/acre compared to 40 elk days/ac for knapweed control areas. Some knapweed would be used by elk but it is unlikely that use would even be close to the 27 elk day loss caused by knapweed. Another aspect of this problem is that heavy concentrated use of grasses in the spring would increase the competitive ability of knapweed over the native grasses, thereby resulting in further decline of grass production on these sites. Even if the increase in knapweed has not resulted in less forage available to wintering elk it most

certainly will increase problems of elk depredation on private property.

During the last decade elk populations have continued to increase as knapweed has increased its dominance in many of the grasslands of western Montana. Much of the increase in elk numbers is probably related to mild winters and not related to improved forage conditions. The largest impact of knapweed on elk winter range maybe that elk will move from knapweed-dominated sites to areas of more preferred forage. These sites will likely be on private property. Elk depredation of hay stacks and of standing vegetation certainly can put undue hardship on private landowners. With the increase in elk numbers problems from elk depredation will certainly increase and will be expensive to the land owner. As private land owners complain about the growing forage use by elk on their property there will be calls for reductions in elk numbers. Therefore, on elk winter range it seems to be very important to keep the site in its most productive capacity. In western Montana we believe that every effort should be made to keep knapweed from these sites. All available evidence indicates that herbicides would be an important management tool to maintain these areas in grassland communities. More research is needed on the use of herbicides to maintain a diverse communities. Herbicides with greater selectivity are certainly desirable but knapweed apparently has the ability to decrease community diversity.

CHAPTER III

RELATIONSHIP OF CRITICAL ENVIRONMENTAL FACTORS TO THE SUCCESS OF SPOTTED KNAPWEED IN WESTERN MONTANA

If we are in our imaginations to give one species an advantage in the struggle for existence probably in no one case would we know what to do (Darwin 1859). Whatever that advantage may be, however, spotted knapweed (Centaurea maculosa L.) does seem to have a definite advantage when growing in Montana. Spotted knapweed was first observed in the state in the 1920s; it now occupies 1,600,000 acres and is present in every county (French and Lacey 1983, Chicoine 1984). Originally an intruder only of disturbed rangelands (Morris and Bedunah 1984), spotted knapweed now exists in nearly every habitat type west of the Continental Divide; it ranges from the driest bitterbrush/ bluebunch wheatgrass (Purshia tridentata/Agropyron spicatum) zone to the lush western hemlock/beadlily (Tsuga heterophylla/ Clintonia uniflora) forest.

After establishing in an area, spotted knapweed density often increases. Simultaneous production of desirable forage decreases, sometimes by as much as 90% (Baker et al. 1979, Harris and Cranston 1979). This causes serious financial losses to ranchers, and it reduces the capacities of big game ranges to produce winter forage (Spoon et al. 1983). Even western Montana's timber producing potential may be threatened because spotted knapweed competes with conifer seedlings for water and

nutrients (Spoon et al. 1983). Also, spotted knapweed has an allelopathic toxin that has inhibited germination of larch (Larix occidentalis) seeds and reduced the growth of larch and lodgepole pine (Pinus contorta) seedlings in laboratory tests (Kelsey and Locken, in press).

More must be known about the ecological tolerances of spotted knapweed before the spread of this weed can be slowed in Montana. Does this weed threaten the productivity of all of Montana's uncultivated lands, or is there a limited combination of environmental factors that allow its success? The objective of this study was to identify the environmental factors that most affect spotted knapweed success in western Montana.

Literature Review

A key to spotted knapweed's success lies in its abundant seed production, which in Montana averages 1000 seeds/plant (Story 1976). Once seeds are present in an area, the weed can colonize soils with a wide range of chemical and physical properties. In fact, Watson and Renney (1974) reported that the only soil property correlated with plant density was degree of soil disturbance.

Although it has been reported that knapweeds are uncommon in shaded areas (Watson and Renney 1974), Spears et al. (1980) found that spotted knapweed germinates equally well over a range of 0 to 100% canopy cover. In addition, Watson and Renney (1974) observed that percent germination in the dark was significantly greater ($P \leq 0.05$) than when 12 hours of exposure to light were

followed by 12 hours of darkness. Continuous light further reduced the percentage of seeds germinating. It appears, then, that low light intensity does not reduce knapweed germination. However, other conditions common to a forest floor, such as a thick litter layer, may hamper knapweed germination and/or survival after germination.

While spotted knapweed seeds will germinate under a broad range of temperatures from 7° to 34° C (Watson and Renney 1974), soil moisture requirements for germination are very specific. Spears et al. (1980) reported 90% germination when soil moisture was 65% or 70%. However, at 75% soil moisture, only 73% of the seeds germinated, while at 55% soil moisture no seedlings emerged.

Soil moisture appears to be a critical element governing time of germination. In eastern Washington, Schirman (1984) observed that during a "wet June" about 70% of planted knapweed seeds emerged and survived. On the other hand, seeds planted during a "dry June" had a low emergence rate.

In another study, Schirman (1981) found that the earlier a seedling emerged in a given year, the greater the chances that it flowered the following year. Seventy to 75% of the plants seeded in March or April flowered one year after germination, while none of those planted in June or July flowered a year later. Hence, timing of precipitation during a particular year impacts knapweed densities for several years into the future.

In addition to influencing when knapweed flowers, precipitation also influences the number of seeds that any one

plant will produce. Schirman (1981) observed that during a wet year more flowers form on each spotted knapweed stem, and more seeds develop within each flower. Unlike many perennial grass plants that require a year to recover vigor after a drought, spotted knapweed responds immediately to moist, favorable conditions (Schirman 1981, 1984). Hence, knapweed seeds may invade bare soil left exposed after perennial forage plants have retreated during drought. Therefore, spotted knapweed stands may expand in pulsations (Morris and Bedunah 1984) whenever rain follows drought.

Surges in spotted knapweed populations after drought could likely occur even if seed production did not increase during wet periods, since this opportunist also produces ample seeds under dry conditions. In British Columbia, Watson and Renney (1974) found that spotted knapweed averaged 436 seeds/plant on dry rangeland as opposed to 25,263 seeds/plant under irrigated conditions. Schirman (1981) reflected that even if only 0.1% of the seeds produced in a year germinated and flourished, stand densities of this weed would remain constant.

Viability tests have shown that 77% of buried spotted knapweed seeds were viable after 12.5 months (Chicoine 1984). After remaining buried in soil for 5 years, 40% were viable if planted 2 inches or deeper, while approximately 20% remained viable when planted at one inch (Schirman 1984). Therefore, even after many years of controlling spotted knapweed on the same site, the soil may still store a viable reserve of seeds.

Spotted knapweed seeds are dispersed when the achene is

flicked from a mature seed head as the parent plant is jarred. This flicking action allows a spotted knapweed stand to expand about a meter outward from its perimeter each year. However, spotted knapweed achenes may also be transported by mammals, birds, humans and vehicles. This allows the weed to become established far from the parent stand and hastens its spread (Strang et al. 1979, Baker et al. 1979, Watson and Renney 1974).

Once a seed source is available the weed may germinate in any patch of bare soil. Gopher mounds, overgrazed range, motor bike tracks, or the natural bare spaces between plants on semi-arid rangeland are all potential sites for spotted knapweed invasion. Even range in excellent condition will support some rodent activity, and will have microsites where knapweed may establish (Morris and Bedunah 1984).

Spotted knapweed was introduced from Europe and Asia; thus, once it is established in Montana, it is rarely preyed upon by diseases or herbivores since it has no natural enemies in North America. In addition, the allelopathic toxin, cnicin, that is produced in knapweed leaves possibly discourages herbivores from developing a preference for the weed (Locken 1985). Therefore, spotted knapweed retains vigor while adjacent plants are selectively grazed.

Spotted knapweed begins growth in late fall or early spring, which is a definite advantage (Watson and Renney 1974). This allows knapweed to capture space, moisture, and nutrients before competitors break dormancy (Harper 1977). In addition, spotted knapweed's allelopathic toxin, cnicin, may reduce growth of

competitors such as bluebunch wheatgrass (Agropyron spicatum) and rough fescue (Festuca scabrella) in rare cases where cnicin is found in high concentrations in the soil (Kelsey and Locken in press, Locken 1985). Therefore, once spotted knapweed is established, it can grow at the expense of more desirable plants. In one study on Blue Mountain near Missoula, Montana, forage production increased from 26 to 852 pounds/acre after a spotted knapweed stand was treated with two annual applications of 2,4-D (Baker et al. 1979).

Methods

Environmental data describing sites where spotted knapweed presently grows were collected throughout Western Montana during the summers of 1984 and 1985. Sites for data collection were located by driving along major and secondary roads west of the Continental Divide. All National Forests were covered, along with as many lands administered by the Bureau of Land Management and the State of Montana, as time permitted. All sites infested with spotted knapweed were sampled as they were encountered. In this way data were collected in each of western Montana's major habitat types, including every area where knapweed is currently a problem. Data collection was concentrated in the more common habitat types and in habitat types where spotted knapweed is more important. Data were collected in grassland and shrubland types only where knapweed infestations were not so dense as to make identification of the habitat type impossible, and where herbicides had not been used to alter the vegetation.

Infestations were rare in wetter habitat types (outside of road ditches) so fewer of these sites were examined. No data were obtained, of course, from areas where knapweed did not occur. Data were collected on 30 sites in the wetter habitat types, 141 sites in the Douglas-fir (Pseudotsuga menziesii) series, 22 sites in the ponderosa pine (Pinus ponderosa) series, and 31 sites in the grass/shrub types (See Appendix 7).

Data Collection

Plant Distance. One of the most important characteristics to be measured at each site was that of spotted knapweed importance. Visual reconnaissance of the site established that the plants were present, but some measurement was needed to describe how important the species was, or how successful it was in establishing a population on that site having those ecological characteristics. Plant density seemed to reflect spotted knapweed's ability to establish and survive on a site. The options were to measure spotted knapweed density directly by counting the number of individual plants in a quadrant, or to measure the mean distance from a point to the nearest knapweed plant. The latter measurement was more convenient and considered adequate for describing the success of the invader on that site.

The closest individual method (Cottam and Curtis 1956) was used to measure plant distance along 200 m transects through the knapweed-infested areas. The direction of the transect was chosen so that it ran through the most representative portion of the knapweed stand, while remaining on the same aspect. At every ten-meter interval along the transect, the distance to the

nearest spotted knapweed plant was measured in meters. If the nearest plant touched the point from which distance was being measured, the distance was recorded as 0.1 m. If the nearest knapweed plant was further than 10 m from the point, the distance was recorded as 10 m.

When a road was adjacent to the study site, average knapweed distance was also measured parallel to the road along 200 m transects.

Site Characteristics. Other site characteristics in addition to plant distance were measured and recorded at each transect location. These included habitat type (Pfister et al. 1977, Mueggler and Stewart 1980), elevation (m), true aspect (aspect-1), degrees from south (aspect-2), percent slope, topographical position, slope configuration, soil texture, and disturbance intensity.

Elevation was measured with an altimeter, percent slope with an Abney level, and aspect with a hand held compass. Soil texture was determined by hand and then recorded as follows: 1 = Clay; 2 = Clay Loam; 3 = Silty Loam; 4 = Loam; 5 = Sandy Loam; and 6 = Loamy Sand.

Topographical position was also a coded variable. The following classes were observed in the field: 1 = Ridge; 2 = Upper Slope; 3 = Mid Slope; 4 = Lower Slope; 5 = Bench or Flat; and 6 = Stream Bottom. However, preliminary analysis showed there were no significant differences between knapweed densities on ridges, upper slopes, and mid slopes, or between densities on lower slopes, benches, and bottoms. Therefore, for this analysis

topographical position classes were lumped so that 1 = Ridge, Upper Slope, and Mid Slope; and 0 = Lower Slope, Bench or Flat, and Stream Bottom. Four classes were recorded for slope configuration: 1 = Concave; 2 = Undulating; 3 = Straight; and 4 = Convex.

The following disturbance classes were recorded for the sites where they applied: logging system; incidence of fire; intensity of rodent activity; intensity of grazing pressure; and presence of mechanical activity, trails, or roads. Subsequently, disturbance categories were translated into a 0 to 100 scale using disturbance keys (See Appendix 6). The objective of the disturbance key was to translate the coded disturbance classes into a continuous variable which accurately reflects the impact of disturbance on a site. For this reason disturbance keys were based on the two variables that control the effect of disturbance: a) amount of bare soil exposed to invading seed, and b) proportion of the site's reproductive capacity which has been lost (Connell and Slayter 1977). A site's reproductive capacity is the combination of seeds being produced by plants growing in the area and of the seeds already stored in the seed bank (Harper 1977).

Originally, four disturbance keys were devised (See Appendix 6), each assigning a different proportion of importance to the amount of bare soil exposed and to the decrease in reproductive capacity. The rating system that explained the most variation in the multivariate factor analysis, and that was used for subsequent statistical analyses, was one that assigned the loss

of a site's reproductive capacity three times the importance of the size and frequency of bare soil openings. For example, a road received 25 points for its entirely exposed bare surface, and 75 points for its complete loss of reproductive capacity. However, the proportion of importance assigned to the loss of reproductive capacity and to percent of bare soil exposed probably was not very important. This is because a disturbance which drastically curtails a site's reproductive capacity also usually creates large open areas free from competing vegetation. For this reason scores of a disturbance class were similar regardless of the rating system used. For example, the class that was described as Clearcut, Burn, Rodents High received a large score from all four systems, while the Grazing Low class was assigned a low number. In fact, when each of the four disturbance variables was used in factor analyses along with the remaining variables, the percent variation of plant distance explained by the factor model varied by only 3.4% - from 68 to 71.4%

Data Analysis

Data were analyzed using the principal components method of factor analysis and with multivariate regression analysis. Data were transformed into Z scores to complete the factor analysis. Residuals were analyzed to determine the normality of the data for the regression analysis. The entire sample was normal as were the subsets of wet habitat types, Douglas-fir habitat types, and ponderosa pine types. However, the dependent variable, distance, was squared in order to normalize the grass and shrub

data subset. Variables were entered using the step method. Both paired t-tests and grouped t-tests were used for the appropiate data. The significance level was 0.05. Statistical analyses are described by Johnson and Wichern (1982) and Ott (1984).

Results

As the site became more dry or more disturbed, the average distance between spotted knapweed plants decreased (Table 4). Since the average distance between plants is much greater in the wet habitat types (See Appendix 7), spotted knapweed is not as successful here as it is in the Douglas-fir series, ponderosa pine series, grass, and shrub types (Appendix 7). Similarly, spotted knapweed is more successful in the pine, grass and shrub types than it is in the Douglas-fir series. Plant distances are also significantly greater on sites with low distubance as compared to sites with medium or high disturbance. Likely, the difference between plant distance on medium- and highly-disturbed sites is not significant because of an interaction with moisture. For example, as much knapweed may grow on a moderately-disturbed dry site as grows on a highly disturbed wet site. The distance between plants is very small along roads suggesting that spotted knapweed is especially successful in an environment that is not only very disturbed, but in many cases provides little competition from other plant species.

Since knapweed stands were rare in those habitat types wetter than the Douglas-fir series (See Appendix 7), few transects were run in these moist types. The extremely small

sample sizes made statistical evaluation of knapweed success between types impossible. Hence, these transects were grouped into the "wet" category.

On the other hand, the fact that few transects were run in these wet types suggests that knapweed is uncommon here. Lack of knapweed could be due to a scarcity of seeds, or to knapweed's failure to germinate, or to competition in wetter habitat types. If lack of seeds were the only factor limiting knapweed success in these wetter types, one would not expect to find such a large difference between plant distance on and off the roads (Appendix 7). Rather, the differences would be small as observed on the following drier types: bitterbrush/bluebunch wheatgrass (*Purshia tridentata*/ *Agropyron spicatum*), big sagebrush/bluebunch wheatgrass (*Artemisia tridentata*/ *Agropyron spicatum*), Idaho fescue/bluebunch wheatgrass (*Festuca idahoensis*/ *Agropyron spicatum*), bluebunch wheatgrass/Sandberg bluegrass (*Agropyron spicatum*/ *Poa sandbergii*), and rough fescue/ bluebunch wheatgrass (*Festuca scabrella*/ *Agropyron spicatum*). However, since the distance between plants is much smaller on roads in wetter types, it appears that spotted knapweed is more successful at germinating and sur-viving in very disturbed environments. As pointed out above, there is a small difference between knapweed success on and off the roads in the driest habitat types. Therefore, disturbance is not as critical to knapweed survival on drier sites.

Factor analysis was performed to determine which environmental variables may interact to affect the distance

between spotted knapweed plants over all habitat types (Table 5). Factor One represents an interaction between high elevations, ridge or upper slope topographic positions, and convex slope configurations. While these three traits generally do coincide on mountain tops, there is almost no relationship between them and knapweed success. While the magnitude of each of their loadings on Factor One is large (0.654, 0.763, 0.536), the loading of plant distance is very small (-0.012). Each loading expresses the proportion of a variable (such as plant distance) that is explained by a given factor (such as Factor One). When a variable has a high loading on a factor, as do distance (0.790) and disturbance(-0.858) on Factor Two, the variable is closely related to that factor. Hence, distance and disturbance are closely related to Factor Two and to each other. Factor Two can be thought of as a disturbance/plant distance interaction. The sign of the loadings reveal the nature of this relationship. The negative disturbance and the positive distance imply that a small amount of dist-urbance is related to a large distance between plants.

Factor Two and Factor Three explain most of the variation (71.4%) of spotted knapweed's average plant distance. Whereas Factor Two is a disturbance/plant distance interaction, Factor Three is probably a moisture stress relationship. Although soil texture (0.833) is strongly related to Factor Three, aspect-2 (-0.519) and percent slope (0.564) are also somewhat related to Factor Three and to soil texture. Positive soil texture symbolizes coarse soil, negative aspect-2 indicates few degrees

from south or a southern exposure, and positive slope suggests steep slopes. Factor Three then is an interaction between coarse soil, southern exposure, and steep slopes, which probably relate to moisture stress. Also, on sites with this combination, bare soil can compose up to 20% of the undisturbed climax community (Mueggler and Stewart 1980). The negative loading for plant distance (-0.300) on Factor Three indicates that distance between knapweed plants is smaller on these drier sites.

Factor analysis was performed with all measured variables (except plant distance) to examine the relationship of disturbance to the other elements (Table 6). The loadings of disturbance, slope configuration, and percent slope are all large on Factor Two. In this case a negative configuration implies concave or moist slopes, and a negative slope indicates gentle slopes. Hence, disturbance was greater on moist, gentle slopes than on dry, steep slopes. Since clearcuts are rarely done on fragile, steep slopes; cattle prefer to graze in valley bottoms or on benches; and rodents generally burrow in deep top soil, mostly in valley bottoms or on benches, it is not surprising that disturbance is greater in these more-resilient environments. Therefore, while the distance between spotted knapweed plants is less in disturbed environments and on moisture-stressed sites, the moisture-stressed sites are less likely to be disturbed.

Several trends in the correlations between plant distance and independent variables are apparent between the wet, intermediate, and dry habitat groups (Table 7). The positive topographic position correlation with plant distance in the wet

Table 4. Average distance between spotted knapweed plants for habitat type groups and disturbance classes.

Habitat Type Groups *	Distance (m)		Disturbance Class		Distance (m)	
Wet	5.71	a**	Low	(0-25)	4.71	a
Douglas-Fir	3.45	b	Medium	(26-50)	3.55	b
Ponderosa Pine	2.24	c	High	(51-99)	2.97	b
Grass/Shrub	2.82	c	Road	(100)	0.88	c

* See Appendix 2 for exact habitat types that were lumped into each group.

**Those mean values within the same column not followed by the same letter are significantly different ($P \leq 0.05$).

Table 5. Factor loadings matrix for knapweed factor analysis.

	Factor One	Factor Two	Factor Three
Plant Distance	-.012	.790	-.300
Disturbance	.003	-.858	-.147
Elevation	.654	-.224	.144
Topographic Position	.763	-.060	-.038
Slope Configuration	.536	.227	.028
Soil Texture	-.149	.005	.833
Aspect-2	-.306	.196	-.519
Percent Slope	.558	.107	.564

Note: The magnitude of each loading expresses the degree of relationship between each variable and the corresponding factor. Amount of variation in plant distance explained by the factor model is equal to the sum of the squared loadings. That is, amount of variation in plant distance explained by this model is:

$$(-.012)^2 + (.790)^2 + (-.300)^2 = .714 \text{ or } 71.4\%$$

group indicates that spotted knapweed is more dense on bottoms, benches, and lower slopes than on middle and upper slopes, and ridgetops. On the other hand, distance between knapweed plants is less on upper slopes and ridgetops in the arid grass and shrub types. Distance between knapweed plants is small on concave slopes in the wet group, and on convex slopes in the dry group. While the weed is much more successful on coarse-textured soils in the wet habitat types, soil texture is not important in the drier types. The intermediate Douglas-fir and ponderosa pine series represent a tension zone of numerous environmental interactions where no measured variable (except disturbance intensity in the pine series) is sufficiently powerful to regulate knapweed success.

The regression equations reflect the correlation statistics (Table 8). In the wet group, distance between spotted knapweed plants is greatly impacted by disturbance and soil texture, and somewhat less by topographic position. In the drier shrub and grass group, aspect is the most important factor, while disturbance also is quite significant. However, in the Douglas-fir and ponderosa pine types there was no regression relationship that explained a high proportion of the variation in knapweed density (none greater than 31%).

Discussion

Success of spotted knapweed on any site is the outcome of a myriad of factors, both abiotic and biotic. Soil texture, aspect, percent slope, competitive vigor of neighboring plants,

and inhibition from allelopathic toxins are all variables that could make the critical difference. However, the importance of each variable changes as the environment becomes more arid (Table 4). For example, in wetter types there is almost no bare soil open to invading plants prior to disturbance. Since initial densities of biennial weed seedlings depend on the percentage of bare ground and on the number of seeds sown (Holt 1972, Gross and Werner 1982), knapweed requires disturbance before it can establish in wet areas that have no natural bare soil component.

Disturbance creates open soil space into which knapweed seeds can invade, germinate, and grow with little competition from neighboring plants. However, once established in wetter areas, spotted knapweed does not seem able to out-compete native vegetation. If it did, knapweed plants would have been common in undisturbed areas at the edge of disturbances. There are several possible reasons why spotted knapweed may not be able to out-compete native vegetation in wetter sites. First, it could be that the allelopathic toxin, cnicin, is leached from the soil before it has any adverse impact on neighboring plants (see Locken 1985). Another possible reason is that many of the plant species which spotted knapweed would be competing with in the forest understory (especially _Arctostaphylos uva-ursi_, _Symphoricarpos albus_, and _Linnaea borealis_) are also not preferred by cattle. Therefore, selective grazing may be a less important advantage for spotted knapweed in the forest. Third, native understory species probably out-compete spotted knapweed because they have evolved advantages for this particular

Table 6. Factor loadings for disturbance factor analysis.

	Factor One	Factor Two
Disturbance	.229	.757
Elevation	.786	.302
Topographic Position	-.703	.067
Slope Configuration	.258	-.620
Aspect-2	-.539	.109
Percent Slope	.634	-.501

Note: The magnitude of each loading expresses the degree of relationship between each variable and the corresponding factor.

Table 7. Correlations of environmental variables with plant distance.

	Wet	Douglas-fir	Pine	Grass/Shrub
Plant Distance	1.000	1.000	1.000	1.000
Elevation	-.137	-.002	.039	-.284
Aspect-1	.148	.152	-.189	.324
Aspect-2	.357	.094	-.125	.460
Slope	-.149	-.066	.005	-.129
Topographic Position	.373	-.157	-.165	-.239
Slope Configuration	.267	.073	-.102	-.197
Soil Texture	-.557	-.227	-.162	.062
Disturbance	-.638	-.164	-.550	-.438

Table 8. Regression models for wet and dry groups.

Site	Model	R^2
Wet	Y = 12.55- .07Disturb- 1.12Texture+ 1.78Topog	.69
Dry	Y = -5.88+ .24Aspect-2 +.12Aspect-1 -.38Disturb	.48

Note: See Appendix 7 for definition of wet and dry groups. Regression models were built using step method. Varibles appear in equation in order of percent of variation explained. For example, in wet habitat types, disturbance explained more variation than texture and topographic position. Each of these variables explained more variation than any other variable, and of any interactions between variables. The independent variable Y is average distance between plants.

environment, unlike the opportunist knapweed. For example, these understory species may retain more vigor under low light intensities than knapweed. Therefore, even though spotted knapweed produces far more seeds when moisture is not limiting, averaging 25,263 seeds/ plant under irrigation as opposed to 436 seeds/plant on dryland (Watson and Renney 1974), spotted knapweed is less successful on wet sites (Table 4).

In the wetter habitats that were sampled, less vegetation probably grew on the better-drained, coarse textured soils, so spotted knapweed competed better here (Table 8). Spotted knapweed's allelopathic toxin, cnicin, may also play a role in the impact of soil texture in wet areas. Cnicin is actually more toxic to spotted knapweed than to any other plant that has been bioassayed (Kelsey and Locken, in press). In wet habitats, cnicin is likely leached out of coarse-textured soils, so that spotted knapweed loses any chemical mechanism limiting its own density.

Aspect probably was not as important a variable when describing distance between knapweed plants in the wetter types because these areas are uncommon on southern exposures (Pfister et al. 1977). Almost all the transects on sites wetter than the Douglas-fir types were on north to east exposures simply because these wetter types almost always occur on cooler exposures in western Montana. Vegetation on wetter types was more affected by factors such as soil texture and the orographic effect which causes more precipitation to fall at higher elevations, limiting knapweed success on upper slopes and ridgetops.

However, in the drier grass and shrub types differences in available moisture caused by soil texture and topographic position are likely smaller because aspect is such a dominating influence. On a southern exposure, soil will dry to permanent wilting capacity of most plants early in summer, regardless of whether the texture is loamy sand or clay loam. Therefore, aspect becomes the dominating variable (Table 8). Unlike wet forests, dry grasslands often have a large component of bare soil in the undisturbed climax community. Hence, spotted knapweed can invade excellent condition range (Morris and Bedunah 1984). While disturbance is not critical for invasion into all grasslands, it increases the chances for knapweed success (Table 8).

A combination of the above scenarios is probably at work in the Douglas-fir and ponderosa pine groups. The situation is especially complicated for the Douglas-fir group since these habitat types span such a range of sites - from dry, exposed southern slopes to lush, north-facingslopes. Disturbance on an arid slope would not be as critical a factor, whereas on the north-facing slope intense disturbance would be necessary. Thus, the amount of disturbance required to allow knapweed to invade varied so that the correlation of plant distance with disturbance was low (Table 7).

Although spotted knapweed produces more seeds on wet sites, it is more abundant on dry sites or on very disturbed sites. Therefore, spotted knapweed on wetter sites must be out-competed by more aggressive plants. It follows that disturbances in wetter habitats must be intense before enough plant competition

has been eliminated to allow knapweed to succeed. On the other hand, the climax range on dry sites (Appendix 7) already has bare soil open to invasion (Mueggler and Stewart 1980). Any small amount of disturbance exposes even more bare soil. Therefore, when considering the range of moisture conditions from the wettest to the driest sites, it appears that the relationship of site disturbance to spotted knapweed success changes as the soil moisture changes (Fig. 44). A much greater intensity of disturbance is required for a given level of spotted knapweed success in wet areas, as opposed to dry areas.

This information is useful in predicting which uncultivated lands in western Montana are vulnerable to knapweed invasion. The above relationship indicates that spotted knapweed will only thrive in grand fir (*Abies grandis*), subalpine fir (*Abies lasiocarpa*), western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) habitat series when the environment is greatly disturbed. However, in the drier habitat types such as bitterbrush/bluebunch wheatgrass, big sagebrush/bluebunch wheatgrass, Idaho fescue/bluebunch wheatgrass, bluebunch wheatgrass/Sandberg bluegrass, and rough fescue/bluebunch wheatgrass, spotted knapweed can enter undisturbed climax rangelands whenever a seed source is present.

Hence, on all the drier rangelands of western Montana where knapweed is already present, land managers should begin to view the weed as a permanent component of the plant community. Rather than attempting to eradicate it, management should be geared toward control. This may be possible by maintaining vigorous

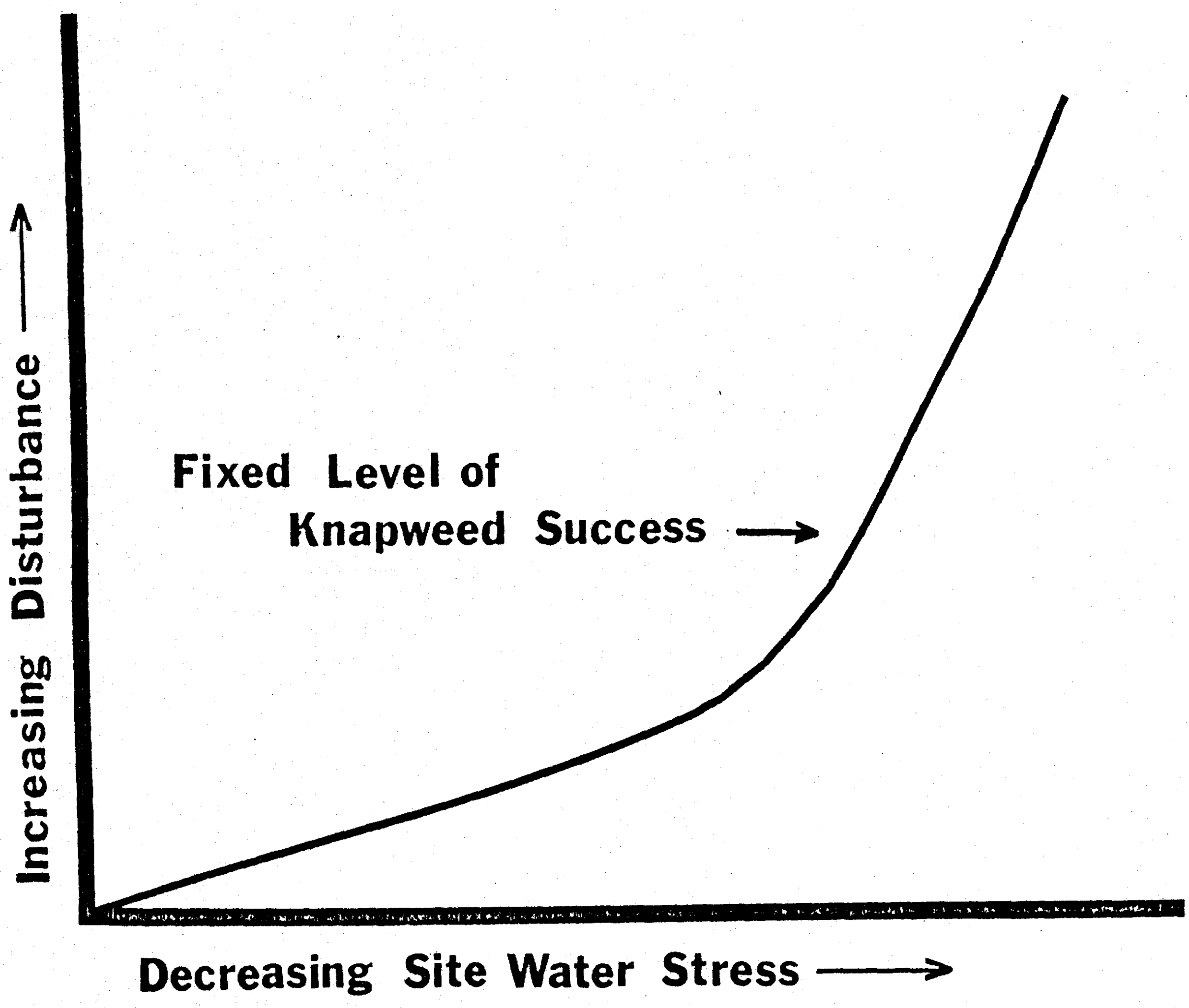

Figure 44. Relationship of site disturbance and moisture relationships to spotted knapweed success.

stands of perennial grasses that provide strong competition for knapweed. Likely, in these good condition ranges spotted knapweed will always thrive on rodent mounds and random bare spaces between grass plants, but it will only spread rapidly when grass vigor has been reduced by drought or overgrazing.

Given the great distribution and large population of spotted knapweed already present as a seed source, there is a high probability that spotted knapweed will eventually invade all drier rangelands in western Montana to some degree. However, disturbance, particularly road building, will accelerate this invasion. In drier rangelands where spotted knapweed has not yet invaded, land managers must begin to factor in the loss of forage production with the cost of building new roads or other forms of site disturbance. Since roads are one of the greatest avenues of spotted knapweed dispersion, the question of spotted knapweed invasion after a road is built is not one of whether it will occur, but when.

Conclusions

While spotted knapweed can be found in almost every habitat type in western Montana, it probably will not become a dominate weed in wetter areas, except on very disturbed sites. However, aspect in grass and shrublands is even more important than disturbance when predicting a site's risk to invasion. In drier sites where a seed source is available, distance between knapweed plants will depend on percent of bare soil in the undisturbed community, and time since initial invasion, as well as aspect and

disturbance intensity. Further investigations should examine the density of knapweed infestations over time to determine if infestations eventually decline, perhaps in response to the weed's own toxin, or if dry sites are continually reinvaded.

CHAPTER IV

USE AND PREFERENCE OF SPOTTED KNAPWEED BY ELK AND MULE DEER ON TWO WINTER RANGES IN WESTERN MONTANA

A weed by definition is "any undesired, uncultivated plant that crowds out desired ones" (Webster 1972). Extensive weed stands on rangelands are the result of past disturbances such as overgrazing by domestic livestock and cultivation of introduced forage crops. Low elevation sites are more accessible, and therefore more susceptible to man-caused disturbances and the spread of weedy plants than high elevation sites. Displacement of native forage by weeds is now an aesthetic and economic problem. One weed in particular, spotted knapweed (*Centaurea maculosa*), has invaded many disturbed sites in western Montana. Currently, there are no wide-scale, effective methods of controlling the spread of this weed.

Several abandoned valley and foothill homesteads in Montana are now dominated by knapweed. Two such sites in the Bitterroot Valley were purchased in the 1960's by the Department of Fish, Wildlife, and Parks for elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) winter ranges. These sites are the Threemile and Calf Creek segments of the Bitterroot Wildlife Management Area, and both have serious knapweed problems.

Does the presence of knapweed alter elk and deer use of these ranges during the winter and spring? A general avoidance

by these animals of areas dominated by knapweed may suggest a lack of interest in this plant due to low forage quality. However, other factors, such as low precipitation or human harassment, could also cause avoidance. During the winter and spring of 1985-86, the forage value of spotted knapweed was assessed by its chemical composition and amount of use by elk and deer on the Bitterroot state ranges. The objectives of this study were: 1) to determine if elk and/or deer were eating spotted knapweed and preferring it to other forage during winter and spring and 2) to assess the forage quality of knapweed by chemical analyses on samples collected during this time period.

Literature Review

People in western Montana have come to easily recognize spotted knapweed. It is a tall, usually shrubby-looking biennial forb, that can grow to 1.5 m tall. The weed's first appearance was documented in Ravalli County in the 1920's and it is now found in every Montana county (French and Lacey 1983). By 1979, knapweed had infested 875,000 ha in Montana, Idaho, and Washington; 810,000 ha were on rangelands in western Montana (Maddox 1979). Harris and Cranston (1979) found that this weed reduced forage production by almost 90% on sites in western Canada, and big game winter ranges with knapweed stands are now labelled unproductive (Spoon et al. 1983).

Montanans agree that knapweed is a major weed problem, but there is much disagreement on its forage value. Do animals really eat it? Cattle eat knapweed during the plant's early and

mid-season growth; goats graze the plant when it's actively growing and then select the mature flower heads; and sheep select knapweed and prefer it over other forage (Spoon et al. 1983). Bohne (1974) reported that elk in the South Fork of Fish Creek in western Montana grazed on knapweed during the summer and winter months. Forage use was 5% and 2%, respectively. Firebaugh (1981), also in western Montana, studied the food habits of mule deer on the Larry Creek Winter Range from 1977-79. Spotted knapweed made up the greatest percentage of forb use during all three years. Percent forage use was 29, 23, and trace (less than 0.5%), respectively.

Kufeld (1972) compiled data from 48 food habit studies of Rocky Mountain elk in the western United States and Canada and listed commonly used forage species. Plants representing less than 1% of the diet were not reported and averages of all studies were used to classify species by value. Knapweed was not on the list. In 1973, Kufeld et al. summarized 99 food habit studies of Rocky Mountain mule deer and followed the same guidelines as before. Again, no knapweed was mentioned. Other food habit studies of elk and mule deer in Montana do not mention the use of knapweed in their diet (Stevens 1966, Mackie 1970, Morris and Schwartz 1957, Lovaas 1958). However, these studies are not representative of areas with major spotted knapweed infestations.

Forage quality is based primarily on a forage's palatability, digestibility and benefits to rumen microorganisms (Wallmo 1980). The reason why a plant is palatable to certain species of animals or even to certain individuals within a

species is often uncertain. Succulency enhances palatability (Oelberg 1956) and the texture of many plants influences whether they are eaten or not. Deer select food on the basis of smell and taste; sweet, sour, and bitter tastes are ranked in decreasing order of palatability (Church 1971).

Cnicin is a bitter-tasting substance present in spotted knapweed. Locken (1985) found concentrations of cnicin in spotted knapweed in glandular trichomes on tissue epidermis. Gland density and cnicin concentrations increased from rosette leaves, to stem leaves, and then to branch leaves, respectively. All dead leaves contained cnicin, proving this substance is not easily leached. Live stems, dead stems, flower heads, and roots had no cnicin concentrations. Locken (1985) summarized cnicin's primary role as that of a protector against herbivores because localized concentrations within the plant can result in maximum herbivore contact with this bitter substance.

Snow depth can also influence food selection by changing a once unpreferred food to a more acceptable one. Skovlin (1982) found that snow depths greater than 61 cm changed an elk's diet from herbaceous plants to one consisting mainly of browse. This diet change is related to the reluctancy of elk to plow through snow and paw for buried grasses and forbs (Geist 1982). Leege and Hickey (1977) also found that elk moved to poorer forage areas when snow depth exceeded 46 to 61 cm.

Moving and foraging in deep and/or crusted snow is energetically costly and therefore avoided by wild ungulates whenever possible. Deer, more than elk, avoid deep snow and

prefer feeding in areas with minimal snow cover (Carter 1951). Geist (1981) stated that deer rarely paw for food because of this feeding site preference and the presence of heavy and crusted snow throughout most of the winter. Deer move to areas where conifer cover limits and softens snow cover (Bouckhout 1972). Snow depths of 46 to 51 cm seriously impede mule deer movement (Carter 1951). Mature elk can move in loose snow up to 122 cm but snow depths over 76 cm greatly hinder calves and weaker animals (Gaffney 1941).

The facial differences between deer and elk suggest an evolutionary adaptation for particular plants and plant community types. The smaller, pointed face of a deer lets it pick and choose small plants or plant parts (Short 1981). Individual bites taken by a deer from a plant average 0.1 g (Carpenter 1975). In contrast, the wider cow-like muzzle of an elk is more adapted for grazing entire or nearly entire plants (Jarmon 1974). Therefore, during the winter, deer are apt to be found most often in forests or along forest edges where food selection is highest and snow conditions are most favorable. Elk selection of community types can be more versatile and unpredictable (Carter 1951).

Jones and Hanson (1985) reviewed the elk and mule deer food habits summary by Kufeld (1972) and Kufeld et al. (1973). They infer that deer are influenced more than elk by forage availability due to snow cover because of the sudden increase of browse use by deer during winter. Wallmo et al. (1977) concur with this thought by stating that woody plants are not suited to

a deer's digestive tract nor to its nutritional requirements. Deer must feed more selectively for easily digested and high protein forage than elk (Geist 1981). Deer need quality, while elk can benefit from quantity because of their larger rumen in relation to their body size (Madson 1986). Once a deer's rumen reaches a threshold capacity (digestive tract fill limits dry matter and energy intake), deer cannot eat much more (Ammann et al. 1973); thus, diets of high fiber and low available energy can cause starvation (Wallmo et al. 1977).

Wallmo et al. (1977) evaluated the nutritional status of mule deer habitat in Middle Park, Colorado. They found that duration and severity of winters were the most important factors in determining deer survival. They suggested that habitat evaluations be based on quantifying nutrient supplies and their availability rather than measuring twig lengths of "key" species.

Protein and energy are the most limiting nutrients during winter (Nelson and Leege 1982). Protein is needed daily for tissue replacement, growth, and reproduction (Lassiter and Edwards 1982). Elk require a maintenance diet consisting of 5 percent protein (Nelson and Leege 1982) while deer require a maintenance diet of at least 7 percent protein (Wallmo 1980). A maintenance diet is "one that adequately supports an animal doing no vital work, making no growth, developing no fetus, storing no fat, or yielding no production" (Cullison 1975). This maintenance requirement is equal to the nitrogen excreted in the urine during starvation and is proportional to body surface (Cullison 1975). Since rumen microorganisms can synthesize

protein from non-protein nitrogen sources, the nitrogen content of forage is important (Nelson and Leege 1982).

Firebaugh (1981) analyzed 7 mule deer forages for percent crude protein during winter and spring. The winter protein content of knapweed flower tops was similar to that found in Idaho fescue (Festuca idahoensis) and arrowleaf balsamroot (Balsamorhiza sagittata); it was lower than that found in elk sedge (Carex geyerii), chokecherry (Prunus virginiana), ceanothus (Ceanothus velutinus), and serviceberry (Amelanchier alnifolia). The spring protein content was found to be higher than elk sedge, Idaho fescue, and ceanothus, but lower than arrowleaf balsamroot, serviceberry, and chokecherry. Two values were listed for the January knapweed collection for the 2 sites sampled.

The low value (2.9%) was the protein content of knapweed growing on dry upland sites where forage use was minimal and the high value (11.6%) was knapweed collected from shaded areas where it was less brittle and received heavy deer use. Laycock and Price (1970) also found that shaded plants are more succulent and contain higher protein contents than those growing in full sunlight. The lignin content has also been found to be higher in shaded plants (Webb 1980). A delay in plant development caused by the presence of the forest canopy seemed to be the principal factor causing these differences (Laycock and Price 1970).

Since carbohydrates (primarily cellulose) make up approximately three-quarters of forage dry matter, they are the main source of energy for animals (Lassiter and Edwards 1982). Cell contents of plants (lipids, starches, sugars, and proteins)

are easily digested and high in energy compared to the cell wall components (cellulose, lignin, silica, and hemicellulose) (Cullison 1975). Lignin resists microbial digestion, and its only value is as a bulk factor (Cullison 1975). The degree of lignification of plant material affects the digestibility of cellulose (McDonald et al. 1973). Cullison (1975) stated that lignin may also reduce the digestibility of other nutrients.

Winter browse contains more protein and soluble carbohydrates than dead forbs or grasses, but they also have higher lignin contents and lower digestibility coefficients (Short 1981). To meet their 7 percent protein maintenance requirement, deer need to consume browse twigs (Wallmo et al. 1977). In Middle Park, Wallmo et al. (1977) found average digestibility of browse to be 34% compared to 42% for grasses. A 50% digestibility coefficient for forage is needed to maintain young deer (Ammann et al. 1973). Milchunas (1977) stated that lignin may enhance passage rates of forage because lignified material is characteristically brittle, breaks down to small sizes, and passes rapidly through the digestive tract. He indicated that this may explain why deer utilize large quantities of forage that contain high amounts of fiber and is low in digestibility.

Three winter nutrition studies conducted in western Montana investigated the effects various diets had on elk by monitoring changes in their weight (Hungerford 1948, Geis 1954, Boll 1958). Browse diets resulted in greatest weight losses. Diets with high digestion coefficients, especially meadow hay and bunchgrass,

were the most effective at maintaining body weight.

Geis (1954) reported that respective average percentages of protein, crude fiber, and lignin for 5 forages fed elk were: meadow hay 6.0, 27.8, and 7.5; bunchgrass 3.5, 36.4, and 8.3; willow (Salix spp.) 6.5, 26.2, and 19.5; serviceberry 6.4, 23.2, and 18.2; and mountain maple (Acer glabrum) 7.0, 32.0, and 16.4.

Study Areas

Threemile game range is located in the Sapphire Mountains approximately 16 km northwest of Stevensville, township 10N and range 18W. Total acreage is 2453 ha. This study was confined to sections 19 and 20 where elevation ranges primarily from 1372 to 1524 m. Precipitation ranges between 305 and 381 mm annually. A weather station at Stevensville provided precipitation and temperature data during the study period (U.S. Dept. of Commerce 1985-86) (Table 9).

Soils belong to the Shook, Stecum series and the Brownlee-Duffy-Ravalli complex; slopes average from 9 to 25% (U. S. Dept. of Agric. 1951). These loams and coarse sandy loams are formed from alluvial sediments washed from weathered granite and are highly erosive. Gullies have developed along upslope vehicle and animal trails.

The study area has a history of cattle and sheep grazing and crop production (Beall 1974). Wheatgrass (Agropyron spp.), orchard-grass (Dactylis glomerata), brome (Bromus spp.), and ponderosa pine (Pinus ponderosa) were planted in the 1950's. The area was bought by the state in 1967.

The climax dominant grasses on these grasslands are Idaho

fescue and bluebunch wheatgrass (Agropyron spicatum). Other grasses and grasslikes include Sandberg's bluegrass (Poa sandbergii), Kentucky bluegrass (Poa pratensis), Canada bluegrass (Poa compressa), bulbous bluegrass (Poa bulbosa) Junegrass (Koeleria cristata), cheat grass (Bromus tectorum), timothy (Phleum pratense), wheatgrasses, bromes, pinegrass (Calamagrostis rubescens), and elk sedge.

Forbs are numerous and include spotted knapweed, lupine (Lupinus spp.), arrowleaf balsamroot, paintbrush (Castilleja spp.), yarrow (Achillea millefolium), cinquefoil (Potentilla spp.), salsify (Tragopogon dubius), arnica (Arnica spp.), strawberry (Fraginus spp.), aster (Aster spp.), vetch (Vicia villosa), pussy-toes (Antennaria spp.), larkspur (Delphinium occidentale), thistle (Cirsium spp.), mullein (Verbascum thapsus), groundsel (Senecio spp.), geranium (Geranium viscosissimum), sorrel (Rumex acetosella), buckwheat (Eriogonum spp.) and tansymustard (Descurainia spp.).

Shrubs include snowberry (Symphoricarpos albus), serviceberry, ninebark (Physocarpus malvaceus), rose (Rosa spp.), chokecherry, willow, red osier dogwood (Cornus stolonifera), elderberry (Sambucus spp.), oregongrape (Berberis repens), and kinnikinnik (Arctostaphylos uva-ursi). Ponderosa pine and Douglas-fir are the dominant trees. Scientific nomenclature follows that of Hitchcock and Cronquist (1976).

Calf Creek game range is approximately 16 km northwest of Hamilton and is located in township 6N and range 19W. Total acreage is 883 ha. Parts of sections 8, 9, 16, and 17 were

Table 9. Temperature (°C) and precipitation (mm) data for Stevensville, Montana, from December 1985 through April 1986.

TEMPERATURE

Month	Average Maximum	Average Minimum	Average	Departure From Normal	High	Date	Low	Date
Dec.	-3.4	-13.6	-8.5	-5.6	7	17	-27	11
Jan.	3.5	-7.1	-1.8	+2.9	12	19	-15	5*
Feb.	4.4	-5.1	-0.3	+0.5	21	24	-17	11
Mar.	13.7	-1.1	6.3	+4.3	24	29*	-6	21*
Apr.	14.9	0.1	7.5	+0.3	26	21	-7	13

PRECIPITATION

Month	Total	Departure From Normal	Greatest Day	Date	Snow and Sleet Total	Snow and Sleet Max Depth On Ground	Snow and Sleet Date
Dec.	7.9	-23.9	4.1	3	190	152	13*
Jan.	39.6	+2.8	12.4	17	218	1753	16
Feb.	70.6	+48.8	18.3	23	356	203	15
Mar.	16.3	-2.8	7.6	9	0	0	-
Apr.	17.5	-5.8	6.6	12	**	**	-

* = Precipitation or temperature extremes occurred on one or more previous dates during the month.

** = Insufficient or partial data.

confined to study sampling. Elevation, topography, slope, and precipitation are similar to the Threemile game range. A weather station at Hamilton provides precipitation and temperature data during the study period (U.S. Dept. of Commerce 1985-56) (Table 10).

Soils belong mainly to the Stecum series and the Brownlee-Duffy-Ravalli complex, and are loams and coarse sandy loams. Soils of the Stecum series are less developed than Shook and Brownlee soils. These soils are shallow, rapidly permeable, excessively drained, and have a low natural fertility (U.S. Dept. of Agric. 1951). Deep gullies are found along several vehicle and animal trails. Exposed alkali soil in the mountain big sagebrush (Artemisia tridentata subspecies vaseyana) area is used by elk, deer, and stray cattle as mineral licks. Two lick areas (an open exposed site and a trench-like unexposed site) were sampled for percent extractable ions using ammonium acetate extracts. Percentages of calcium and magnesium were fairly high and similar for both sites. Average percents were 55.60 and 7.05 me/100g, respectively. Sodium content was extremely high. The soil from the unexposed lick had a sodium content approximately 3 times higher than the soil from the exposed lick; 32.4 and 11.1 me/100g, respectively. Licks were used mainly in the spring in association with forage green-up.

Remnants of introduced forage plants, decadent orchards, windrows of caragana (Caragana sp.), and a high density of big sagebush are evidence of a past history of crop production and livestock grazing. The state bought the land in 1960.

Table 10. Temperature (°C) and precipitation (mm) data for Hamilton, Montana, from December 1985 through April 1986.

TEMPERATURE

Month	Average Maximum	Average Minimum	Average	Departure From Normal	High	Date	Low	Date
Dec.	-2.7	-13.3	-8.0	-5.9	9	17	-25	11
Jan.	5.3	-5.3	0.0	+3.9	13	18*	-16	4
Feb.	5.1	-4.7	0.2	+0.3	20	24	-16	11
Mar.	13.7	-0.3	6.7	+4.3	23	27	-6	15
Apr.	14.9	0.1	7.5	+0.3	26	21	-7	13

PRECIPITATION

Month	Total	Departure From Normal	Greatest Day	Date	Snow and Sleet Total	Snow and Sleet Max Depth On Ground	Snow and Sleet Date
Dec.	9.9	-20.3	5.1	2	**	152	4*
Jan.	22.9	-10.4	6.4	17	**	152	5*
Feb.	72.9	+54.6	20.3	17	**	203	15*
Mar.	25.4	+7.4	9.1	9	**	**	-
Apr.	17.5	-5.8	6.6	12	**	**	-

* = Precipitation or temperature extremes occurred on one or more previous dates during the month.

** = Insufficient or partial data.

The climax grasses in the area are rough fescue, (*Festuca scabrella*), Idaho fescue, and bluebunch wheatgrass. Plant composition is similar to that found on the Threemile Range except for the presence of alkali grasses such as alkali bluegrass (*Poa juncifolia*) and interrupted apera (*Agrostis interrupta*); curly-cup gumweed (*Grindelia squarrosa*); and a high coverage of rubber rabbitbrush (*Chrysothamnus nauseosus*) and mountain big sagebrush.

Methods

Study sites were located in the fall of 1985. Two sites in the Bitterroot Valley were established because of their high knapweed infestations and the length of time spotted knapweed has been on these and surrounding areas.

Knapweed Density Measurements

Density of knapweed was measured in the fall of 1985 on selected areas on both ranges using the closest individual method (Cottam and Curtis 1956). Measurements were taken every 10 m along a line transect. Distance was recorded as 10 m if a knapweed plant was further than 10 m from the measuring point and recorded as 0.1 m if on the measuring point. Knapweed seedlings with less than 3 leaves were not included in density measurements. Open sites (grasslands dominated by knapweed), scattered pine sites (open sites with an overstory of Ponderosa pine less than 3.0 m tall), and forested sites (areas with a tree overstory) were sampled on the Threemile game range. Open sites and sagebrush sites (open sites with an overstory of big

sagebrush) were sampled on the Calf Creek game range.

The original intention for measuring knapweed density was to delineate 3 separate areas of low, moderate, and high knapweed density classes and to determine through winter observations if deer and elk avoid certain density classes. Because density variation was high in all chosen areas, distinct classes could not be identified and any statements about area avoidance or selection will not pertain to knapweed densities.

Spotted Knapweed Collections

December use observations of knapweed showed that only the flower tops were being selected and eaten by deer and elk. Therefore, only the dried flowers and upper 0.4 to 0.8 cm of stems were collected for nutrient analyses. Monthly collections of plant tops from the Threemile game range began in December and ended in April. Samples were collected from 5 forested and 5 open sites. All sites had similar exposure, slope, and elevation. Samples taken from forested sites were from small openings where a 5-month supply of knapweed was growing.

Samples were dried in an oven at 60°C oven and then ground in a Wiley mill using a 40 mesh screen. Samples were then used to determine nitrogen content, using procedures outlined by Harris (1970). Percent nitrogen in a sample was multiplied by a factor of 6.25 to calculate percent crude protein. This was done on the assumption that average feed proteins contain 16% nitrogen (Cullison 1975). Therefore, an approximate or crude percent of protein was determined. Percent acid-detergent fiber and permanganate lignin was determined using procedures outlined by

Goering and Van Soest (1970).

All analyses of plant chemical constituents were duplicated and the means were used in statistical analyses. Analysis of variance, at the 0.05% significance level, was performed to detect any difference in the percent crude protein, fiber, or lignin content of the knapweed flowers from the 2 sites, during the 5 months, or a combination of factors involving sites and months (Ott 1984).

Deer and Elk Pellet Collections

Deer and elk pellet samples were collected monthly from December through April on both game ranges. Pellets were dried and packaged with salt. They were then mailed to the Composition Lab at the University of Colorado in Fort Collins where they were analyzed for forage composition using microhistological analyses (Hansen et al. 1979). Monthly pellet samples from elk and deer consisted of 20 pellets, with a maximum of 2 pellets from 10 individual deer or elk pellet groups. The 20 pellets, or individual monthly pellet samples, were ground in a Wiley mill through a 20 mesh (1 mm opening) screen. Equal representative portions from samples were placed on 4 slides and 20 observations/slide were measured for plant species frequency. Frequency numbers were converted to density. A mean density and a 95% confidence interval were calculated from measurements taken from the 4 slides.

Deer pellets are those of mule deer, except that those collected in April on Calf Creek may have been from white-tailed deer (*Odocoileus virginianus*).

Deer and Elk Plant Use and Preference

Plant use by deer and elk was determined by following their tracks and counting the number of bites (Cole 1956) taken from a rooted grass, sedge, or forb; or from a leader of a shrub or tree. Measurements were confined to areas containing spotted knapweed and during days of snowfall when tracks were fresh or when snow cover remained constant. All feeding sites were sampled only once, thereby reducing the possibility of counting previous bites. Only those bites that could be identified as recent bites were recorded. Recent bites from a plant were those that visually resembled freshly broken ends of the plant. Use was also measured as estimated dry weight removed from a plant (Table 11). Plant parts, associated with bites, were clipped in the field and taken to the laboratory where they were dried and then weighed in grams. This type of measurement estimated volume of forage consumed rather than frequency of bites from forage. Therefore, this method seemed more accurate for calculating preferences for different forage species.

Availability of plant species and plant groups (i.e. shrubs) was recorded as percent canopy coverage (Pfister et al. 1977). Availability of plants was ocularly measured on feeding sites approximately 1.0 m on all sides of deer or elk tracks. Only those plants that extended above the snow were measured. An individual plant was assigned to a plant group when specie identification could not be made. The grass category was mainly <u>Poa</u> spp. and the shrubs were deciduous. Plants with a coverage of less than 1%, 1 to 5%, 5 to 25%, or over 25% were labelled

trace, common, well represented, or abundant, respectively.

A preference number was calculated from a ratio of use (total number of bites or weight removed from a plant species or plant group) to availability (the median number of a cover class). The median numbers were used as averages for the cover groups. As an example, preferences for aster and knapweed were calculated as follows: 59 bites of aster with common coverage (59/2.5 = 23.6) and 500 bites of knapweed with well represented coverage (500/15 = 33.3). In this example, knapweed had a higher preference value than aster and was preferred.

Biomass Measurements

In the spring of 1986, an average crown canopy coverage of understory plants, frequency of these plants, and biomass (kg/ha) of plant species and litter was measured on the same knapweed density sites, except knob areas were sampled instead of forested sites on the Threemile game range. A knob site was a highly sloping open site that had not been subjected to cultivation. Density of knapweed on these sites was low and use of these sites by elk and deer was observed in winter and spring.

Crown canopy coverage of species was ocularly measured in a 49.5 cm x 49.5 cm plot frame. Each site was sampled 20 times. Frequency for a plant species was measured as the percent of the plots that contained that species. Three frames were clipped to obtain a measure of plant production and litter. Plant species and litter were placed into separate labelled bags, dried in an oven, and then weighed in grams. A factor of 42.7 was used to convert g/plot to kg/ha.

Table 11. Weights (g) associated with 1 bite taken from various plant species.

aster	0.10 (top)
Douglas-fir	0.20 (needle bundle)
grass	0.05 (top) 1.00 (all)
kinnikinnik	0.10
knapweed	0.05 (smaller top) 0.10 (larger top)
lupine	0.10 (small) 0.25 (medium) 0.50 (large) 1.00 (all)
mullein	0.80 (top)
oregongrape	0.10 (leaf and stem) 1.00 (stem top and 3 leaves)
ponderosa pine	0.07 (fascicle) 0.32 (smaller needle bundle) 0.75 (larger needle bundle)
rose	0.10
sagebrush	0.05 (flower top) 0.10 (leaf top)
salsify	0.05 (top)
serviceberry	0.10
snowberry	0.05
thistle	0.50 (top)
unknown forbs	0.05 (smaller top) 0.10 (larger top)

Observed spring use of knapweed by deer or elk was limited to bites taken from green rosette leaves. Use was reported from that seen in cover and biomass plots on both ranges, from any other observed use, and from pellet samples.

Results

Plant Measurements

Spotted knapweed density on the Threemile game range was 90 plants/m^2 on open sites, 47 plants/m^2 on scattered pine sites, and less than 1 plant/m^2 on forested sites. The high knapweed density measured on open sites was due to the presence of fall seedlings. Average canopy cover and biomass of knapweed were lower on open sites than on scattered pine sites (Tables 12, 13). Open sites had less total biomass and a higher percentage of bare ground compared to scattered pine sites. This bare ground allowed for fall growth of knapweed seedlings. Pedestaled plants are characterisic on both the open sites and scattered pine sites. Spotted knapweed was the dominant forb on these sites and bluegrasses were the dominant grasses.

Knob sites had the highest canopy coverage and biomass of the 3 sites. These areas were the most productive and least disturbed. Balsamroot and lupine were the dominant forbs and Idaho fescue was the dominant grass.

Spotted knapweed density on the Calf Creek game range was 74 plants/m^2 on open sites and 59 plants/m^2 on sagebrush sites.

Knapweed cover and production were similar on both sites (Tables 14, 15). An average higher percent bare ground cover on open sites and the presence of sagebrush on sagebrush sites caused the difference in site density measurements. Knapweed was the dominant forb and bluegrasses were the dominant grasses.

Knapweed Chemical Analyses

Crude protein of knapweed flowers when dormant ranged from 5.3% to 7.7%, with a mean of 6.6% (Table 16). Fiber and lignin contents averaged 45.6% and 14.5%, respectively. Percent crude protein in the dried knapweed flowers was found to be similar for open and forested sites (Table 17). A significant difference ($P \leq 0.05$) was detected between the fiber and lignin contents of the flowers from the 2 sites; percents were higher in the forested sites. Fiber was approximately 4% higher in the forested sites and lignin was approximately 2% higher. No significant seasonal changes occurred in the percent crude protein, fiber, or lignin content of the knapweed flowers from December through April on either site. Therefore, any variation in percent chemical constituents during these months is explained by a variation in the chemical content among the plants on each site.

Pellet Analyses

During winter, all plants have a relatively high fiber content compared to other seasons. Therefore, in reviewing the pellet analyses, it is assumed there is a direct relationship between the relative density of plant fragments in animal pellets and the percent of a species consumed.

Threemile Deer. Shrubs received the most deer use of all

Table 12. Average canopy cover (%) and frequency (%) of understory plant species on the Threemile game range.

	SITES					
	OPEN		SC. PINE		KNOB	
	Cover	Freq.	Cover	Freq.	Cover	Freq.
FORBS						
Achillea millefolium			T[1]	5	T	25
Antennaria spp.					1.4	15
Balsamorhiza sagittata					27.6	70
Castelleja spp.					1.2	15
Centaurea maculosa	44.5	100	47.5	100	3.0	30
Delphinium occidentale					T	5
Erigeron compositus	T	5				
Fraginus spp.			T	5		
Lithospermum ruderale					1.2	5
Lomatium spp.					0.5	10
Lupinus spp.	6.8	55	5.7	45	3.0	60
Potentilla spp.			1.7	20		
Rumex acetosella	T	10	T	5		
Tragopogon dubius					2.7	30
Vicia villosa			2.3	35		
Other forbs	1.5	80	0.8	100	2.8	75
GRASSES						
Agropyron spicatum					2.7	40
Agropyron spp.			T	5		
Bromus tectorum					3.0	10
Festuca idahoensis					20.8	80
Koeleria cristata	1.8	15	3.3	20	3.4	50
Poa compressa & *Poa pratensis*	4.4	55	6.0	85		
Poa sandbergii	8.2	70	3.2	55	2.5	50
Stipa comata	T	5				
TREE SEEDLINGS						
Ponderosa pine			T	5		
TOTAL	67.2		70.5		75.8	
Bare ground & litter	32.8		29.5		24.2	

1/ T ≤ 0.5%

Table 13. Average biomass (kg/ha) of understory plant species and litter on the Threemile game range.

	SITES		
	OPEN	SCATTERED PINE	KNOB
FORBS			
Achillea millefolium			12.8
Balsamorhiza sagittata			462.2
Castilleja spp.			8.6
Centaurea maculosa	479.3	642.0	
Lupinus spp.	17.1	94.2	402.3
Tragopogon dubius			17.1
Vicia villosa		47.0	
Other forbs	30.1		
GRASSES			
Agropyron spicatum			162.6
Bromus tectorum			4.3
Festuca idahoensis			590.6
Koeleria cristata	38.5		179.8
Poa pratensis	98.4	192.6	
Poa sandbergii	111.3	51.3	162.6
TOTAL FORBS & GRASSES	774.7	1027.1	2002.9
LITTER			
B. sagittata			145.5
Grasses	51.3	282.5	470.2
C. maculosa (down)	847.4	492.1	42.8
C. maculosa (standing)	676.2	693.3	
Lupinus		8.6	
TOTAL LITTER	1574.9	1476.5	658.5

Table 14. Average canopy cover (%) and frequency (%) of understory plant species on the Calf Creek game range.

	SITES			
	OPEN		SAGEBRUSH	
	Cover	Freq.	Cover	Freq.
FORBS				
Achillea millefolium			T[1]	5
Centaurea maculosa	32.3	95	33.6	100
Lupinus spp.			15.2	50
Medicago sativa	4.2	30		
Other forbs	5.2	85	2.1	45
GRASSES				
Agropyron cristatum	T	10		
Agropyron spicatum			0.8	15
Agrostis interrupta	9.9	70	1.9	55
Bromus tectorum	1.2	15	T	5
Koeleria cristata			1.2	20
Poa bulbosa			1.4	20
Poa compressa	0.6	10	1.2	10
Poa juncifolia	14.7	85		
Poa pratensis	T	5	5.5	30
Poa sandbergii			5.6	75
TOTAL FORBS & GRASSES	68.1		68.5	
Bare ground & litter	31.9		31.5	

1/ T $\leq$ 0.5%

Table 15. Average biomass (kg/ha) of understory plant species and litter on the Calf Creek game range.

	SITES	
	OPEN	SAGEBRUSH
FORBS		
Artemisia frigida	47.0	
Centaurea maculosa	616.2	624.9
Lupinus spp.		338.1
Medicago sativa	47.0	
Other forbs	72.8	42.8
GRASSES		
Agropyron cristatum	12.8	
Agropyron spicatum		64.2
Agrostis interrupta	8.6	0.4
Bromus tectorum	29.9	
Koeleria cristata		42.8
Poa bulbosa		4.3
Poa compressa	34.2	
Poa juncifolia	701.9	
Poa pratensis	4.3	300.0
Poa sandbergii		89.9
TOTAL FORBS & GRASSES	1574.7	1507.4
LITTER		
Grasses	539.3	
C. maculosa (down)	1575.0	1112.8
C. maculosa (standing)	376.6	136.9
TOTAL LITTER	2490.9	1249.7

plant groups (Table 18). December through April percentages were 48.0%, 63.2%, 47.0%, 51.1%, and 52.2%, respectively. Oregongrape was the most utilized shrub during all months except in April when Rubus was was the main shrub consumed. Ceanothus (Ceanothus velutinus) was consumed in December and January and willow was the only deciduous shrub that received any appreciable amount of forage use in March.

Ponderosa pine and Douglas-fir made up approximately one-quarter of the deer diet, with a peak 47.0% use in February. Tree use by deer was observed only on young trees.

Forbs were utilized most often in December, March, and April. Those most consumed during these months were balsamroot, pussy-toes (or thistle), and lupine. Knapweed use from December through April was 10.2%, 3.8%, 1.5%, 4.7%, and 2.6%, respectively.

Grasses were not an important component of the deer diet. Highest use was in March when they comprised 5.3% of the total forage diet.

Threemile Elk. Grasses had the highest percentage of forage use in February (54.4%), March (59.0%), and April (82.0%) (Table 19). Grass use was dominated by fescue during all months.

Forbs were the dominate forage in the diet during December (55.6%) and January (48.5%). Lupine was the main forb in the diet. Knapweed was consumed in December, January, and February; use was 12.7%, 13.1%, and 2.0%, respectively. March and April pellet samples indicate no knapweed was consumed during these months.

Table 16. Mean percent chemical composition of dried flowers and upper stems of spotted knapweed from open and forested sites on the Threemile game range.

Month	Cover Type	Percent Oven-Dry Weight		
		Crude Protein	Fiber	Lignin
Dec.	Open	6.4[a]	44.2	14.3
Dec.	Forest	6.5	47.6	15.4
Jan.	Open	6.5	42.9	13.4
Jan.	Forest	6.5	45.6	15.0
Feb.	Open	7.1	43.1	13.3
Feb.	Forest	7.7	46.9	16.1
Mar.	Open	6.9	43.5	13.6
Mar.	Forest	6.0	48.8	15.5
Apr.	Open	6.8	44.1	12.8
Apr.	Forest	5.3	49.3	15.0

a/ Each chemical value is the mean of 5 samples.

Table 17. Analysis of variance for chemical components of dried flowers and upper stems of spotted knapweed samples collected from open and forested sites on the Threemile game range.

Source	Df	F-Test Statistic		
		Crude Protein	Fiber	Lignin
Cover Type (CT)	1	0.16	37.62*	63.73*
Month (M)	4	0.25	1.76	1.82
CT x M	4	0.19	0.53	1.82
Residual	40			

*Significant, $P \leq 0.05$.

Table 18. Mean ($\bar{x}$) relative density $\pm$ a 95% confidence interval (CI) of discerned plant fragments found in deer pellet samples[1] on the Threemile game range from December 1985 through April 1986. Calculations are based on data from 4 slides, with 20 fields of observations/slide.

	DEC $\bar{x} \pm$ CI	JAN $\bar{x} \pm$ CI	FEB $\bar{x} \pm$ CI	MAR $\bar{x} \pm$ CI	APR $\bar{x} \pm$ CI
GRASSES & GRASSLIKES					
Carex	1.6 ± 2.9	---	0.5 ± 1.6	1.1 ± 2.1	---
Festuca	1.3 ± 2.5	---	---	2.6 ± 2.3	---
Koeleria cristata	---	---	---	---	0.7 ± 2.1
Poa	0.6 ± 1.8	---	---	1.5 ± 1.7	---
TOTAL	3.5	---	0.5	5.2	0.7
FORBS					
Antennaria - Cirsium	---	---	---	9.1 ± 2.5	---
Artemisia frigida	---	---	---	0.6 ± 1.8	---
Astragalus	---	---	---	---	2.1 ± 6.7
Balsamorhiza sagittata	11.8 ± 11.8	---	---	0.9 ± 1.7	2.8 ± 3.1
Centaurea maculosa	5.0 ± 3.4	2.4 ± 2.9	1.5 ± 3.1	4.7 ± 7.1	2.6 ± 3.0
Centaurea seed	4.7 ± 6.0	0.8 ± 2.7	---	---	---
Descurainia	---	---	---	0.6 ± 1.8	4.4 ± 9.0
Flower[2]	0.6 ± 1.8	0.5 ± 1.6	---	---	---
Lesquerella	---	---	---	0.5 ± 1.6	1.0 ± 3.3
Lupinus	3.5 ± 4.3	2.3 ± 5.2	4.5 ± 3.0	---	11.9 ± 19.1

Table 18 Continued.

	DEC $\bar{x} \pm CI$	JAN $\bar{x} \pm CI$	FEB $\bar{x} \pm CI$	MAR $\bar{x} \pm CI$	APR $\bar{x} \pm CI$
Medicago - Melilotus	---	---	---	---	1.0 ± 3.3
Seed	2.1 ± 2.4	1.1 ± 3.5	---	---	
Unknown forbs	---	0.5 ± 1.6	---	0.4 ± 1.2	
TOTAL	27.7	7.6	6.0	16.6	25.8
SHRUBS					
Berberis repens	33.6 ± 8.8	41.1 ± 8.3	45.8 ± 2.9	38.6 ± 11.8	12.0 ± 13.2
Ceanothus velutinus	14.3 ± 5.5	22.1 ± 12.3	---	---	---
Physocarpus malvaceus	---	---	0.7 ± 2.2	---	---
Rubus	---	---	---	0.9 ± 1.8	40.2 ± 19.2
Salix	---	---	---	11.6 ± 2.4	---
TOTAL	47.9	63.2	46.5	51.1	52.2
TREES					
Pinus ponderosa	18.8 ± 9.1	18.9 ± 8.3	25.5 ± 13.0	17.7 ± 6.6	10.2 ± 8.2
Pseudotsuga menziesii	2.1 ± 2.3	10.3 ± 4.9	21.5 ± 14.1	9.2 ± 6.1	11.1 ± 5.5
TOTAL	20.9	29.2	47.0	26.9	21.3

[1] Deer pellet samples consist of 20 pellets collected from 5, 10, 10, 10, and 9 pellet groups for December, January, February, March, and April, respectively.

[2] Flower is probably that of *Centaurea*.

Total shrub and tree use was highest in January, February, and March. Oregongrape received the highest shrub use and Douglas-fir the highest tree use during all months.

<u>Calf Creek Deer</u>. The major deer forage during all months was trees (Table 20). Monthly use was 75.4%, 61.7%, 43.5%, 74.8%, and 47.1%, respectively. More Douglas-fir than ponderosa pine was consumed.

Shrub use, predominately oregongrape, was highest in January and February. <u>Rubus</u> was consumed in April.

Forbs were utilized most frequently in December, March, and April. Knapweed was the forb most often consumed during all months except February when balsamroot received more use. Percent monthly consumption of knapweed during the study period was 9.6%, 4.1%, 2.3%, 5.8% and 12.8%, from December through April. Consumption of lupine and balsamroot was highest in April.

Grass was not an important forage. Highest grass use was 6.4% of the diet in April.

<u>Calf Creek Elk</u>. Elk consumed a high percentage of grasses, mainly fescue, throughout the study period (Table 21). Total grass use during December through April was 81.9%, 72.0%, 85.6%, 68.3%, and 91.3%, respectively.

Forb use was highest in December and March. Knapweed was the most frequently consumed forb in December (11.1%), January (3.9%), February (5.2%), and March (7.0%). Pellet analyses indicate knapweed was not utilized in April.

Shrub use was minimal, but dominated by oregongrape.

Table 19. Mean ($\bar{x}$) relative density $\pm$ a 95% confidence interval (CI) of discerned plant fragments found in elk pellet samples[1] on the Threemile game range from December 1985 through April 1986. Calculations are based on data from 4 slides with 20 fields of observations/slide.

	DEC	JAN	FEB	MAR	APR
	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI
GRASSES & GRASSLIKES					
Agropyron	1.4 ± 2.7	6.4 ± 8.5	---	0.6 ± 2.1	---
Bromus	---	---	---	---	2.1 ± 2.6
Carex	3.1 ± 3.6	0.9 ± 2.9	5.8 ± 6.6	14.3 ± 10.8	6.3 ± 7.9
Festuca	16.8 ± 11.3	18.4 ± 18.7	42.0 ± 23.5	37.0 ± 17.8	61.6 ± 15.7
Grass seed & glume	0.8 ± 2.7	---	---	---	---
Hordeum jubatum	---	---	---	---	0.5 ± 1.7
Koeleria cristata	---	---	---	---	1.0 ± 3.2
Poa	2.3 ± 2.5	1.7 ± 3.1	6.6 ± 8.4	4.9 ± 6.7	10.5 ± 4.1
Sitanion hystrix	0.9 ± 2.8	---	---	0.7 ± 2.2	---
Stipa comata	0.9 ± 2.8	---	---	1.4 ± 4.4	---
TOTAL	26.2	27.4	54.4	58.9	82.0
FORBS					
Artemisia frigida	5.5 ± 6.0	1.0 ± 3.3	---	2.0 ± 4.1	0.6 ± 1.8
Astragalus	0.8 ± 2.5	---	---	---	1.6 ± 3.1
Balsamorhiza sagittata	1.5 ± 2.9	---	---	0.7 ± 2.2	---

Table 19 Continued.

	DEC	JAN	FEB	MAR	APR
	$\bar{x} \pm CI$	$\bar{x} \pm CI$	$\bar{x} \pm CI$	$\bar{x} \pm CI$	$\bar{x} \pm CI$
Boraginaceae	0.9 + 2.8	---	---	---	---
Centaurea maculosa	1.6 ± 3.0	0.9 ± 2.8	1.4 ± 2.5	---	---
Centaurea seed	8.0 ± 5.7	5.7 ± 7.7	---	---	---
Descurainia	---	---	0.5 ± 1.5	---	---
Equisetum	0.8 ± 2.7	---	---	---	---
Flower[2]	3.1 ± 4.2	6.6 ± 6.0	0.7 ± 2.1	---	---
Lupinus	29.5 ± 16.3	15.3 ± 16.4	2.1 ± 4.5	0.7 ± 2.2	0.5 ± 1.7
Phlox	---	---	---	---	0.5 ± 1.7
Seed	0.9 ± 2.8	0.8 ± 2.6	1.2 ± 2.2	---	---
Verbascum thapsus	2.2 ± 4.3	16.1 ± 10.9	---	1.4 ± 2.5	---
Unknown forbs	0.8 ± 2.7	2.1 ± 6.7	---	---	1.1 ± 2.0
TOTAL	55.6	48.5	5.9	4.8	4.3
SHRUBS					
Berberis repens	11.9 ± 4.3	6.4 ± 5.4	17.5 ± 3.9	19.4 ± 9.6	7.8 ± 8.3
Ceanothus velutinus	0.7 ± 2.1	---	3.8 ± 2.5	9.7 ± 3.6	0.5 ± 1.7
Salix	---	---	---	---	1.6 ± 3.1
TOTAL	12.6	6.4	21.3	29.1	9.9

Table 19 Continued.

	DEC	JAN	FEB	MAR	APR
	$\overline{x} \pm CI$	$\overline{x} \pm CI$	$\overline{x} \pm CI$	$\overline{x} \pm CI$	$\overline{x} \pm CI$
TREES					
Pinus ponderosa	---	4.5 ± 10.9	3.1 ± 1.0	1.4 ± 4.5	1.1 ± 2.0
Pseudotsuga menziesii	5.6 ± 2.9	13.2 ± 15.9	15.3 ± 7.7	5.8 ± 6.9	2.7 ± 3.3
TOTAL	5.6	17.7	18.4	7.2	3.8

[1]Elk pellet samples consist of 20 pellets collected from 10, 10, 8, 10, and 10 pellet groups for December, January, February, March, and April, respectively.

[2]Flower is probably that of *Centaurea*.

Table 20. Mean ($\bar{x}$) relative density $\pm$ a 95% confidence interval (CI) of discerned plant fragments found in deer pellet samples[1] on the Calf Creek game range from December 1985 through April 1986. Calculations are based on data from 4 slides, with 20 fields of observations/slide.

	DEC	JAN	FEB	MAR	APR
	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI
GRASSES & GRASSLIKES					
Carex	---	---	---	---	1.0 $\pm$ 3.2
Festuca	0.6 $\pm$ 1.0	---	---	---	1.6 $\pm$ 5.0
Juncus	---	---	---	---	0.6 $\pm$ 2.1
Koeleria cristata	---	0.5 $\pm$ 1.4	---	---	0.6 $\pm$ 2.1
Poa	---	0.6 $\pm$ 1.7	---	---	2.5 $\pm$ 4.8
TOTAL	0.6	1.1	0.0	0.0	6.3
FORBS					
Artemisia frigida	---	---	---	1.3 $\pm$ 2.4	---
Astragalus	0.6 $\pm$ 1.0	---	---	---	---
Balsamorhiza sagittata	---	---	2.3 $\pm$ 0.5	---	7.3 $\pm$ 3.0
Boraginaceae	---	1.2 $\pm$ 2.3	0.6 $\pm$ 1.8	---	---
Centaurea maculosa	3.3 $\pm$ 1.3	1.1 $\pm$ 3.6	1.0 $\pm$ 1.9	0.6 $\pm$ 2.0	12.0 $\pm$ 7.6
Centaurea seed	6.3 $\pm$ 8.8	2.9 $\pm$ 3.2	1.2 $\pm$ 2.3	5.2 $\pm$ 5.3	0.8 $\pm$ 2.4
Composite	---	---	0.5 $\pm$ 1.6	---	1.0 $\pm$ 3.2
Descurainia	---	---	---	0.6 $\pm$ 2.0	0.7 $\pm$ 2.4

Table 20 Continued.

	DEC	JAN	FEB	MAR	APR
	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI	$\bar{x} \pm$ CI
Lupinus	2.5 ± 3.3	---	1.6 ± 1.7	---	5.7 ± 3.4
Medicago - *Melilotus*	---	---	---	---	1.4 ± 2.6
Seed	---	---	---	1.1 ± 2.1	---
Verbascum thapsus	2.5 ± 4.8	0.5 ± 1.4	0.6 ± 1.8	1.3 ± 2.3	---
TOTAL	15.2	5.7	7.8	10.1	28.9
SHRUBS					
Artemisia tridentata	---	---	---	---	0.8 ± 2.4
Berberis repens	7.9 ± 6.3	29.9 ± 11.8	48.7 ± 14.3	13.4 ± 10.2	3.8 ± 7.4
Ceanothus velutinus	---	1.0 ± 1.8	---	---	---
Chrysothamnus nauseosus	0.9 ± 2.9	---	---	---	---
Rosa	---	0.7 ± 2.4	---	---	---
Rubus	---	---	---	---	12.1 ± 10.5
Salix	---	---	---	1.1 ± 2.1	---
Shepherdia canadensis	---	---	---	---	1.0 ± 3.2
Unknown shrubs	---	---	---	0.6 ± 1.7	---
TOTAL	8.8	31.6	48.7	15.1	17.7

Table 20 Continued.

	DEC	JAN	FEB	MAR	APR
	$\bar{x} \pm CI$	$\bar{x} \pm CI$	$\bar{x} \pm CI$	$\bar{x} \pm CI$	$\bar{x} \pm CI$
TREES					
Pinus	15.9 ± 13.9	27.5 ± 9.9	8.4 ± 1.6	21.1 ± 16.6	1.8 ± 3.3
Pseudotsuga	59.5 ± 20.9	34.1 ± 5.1	35.1 ± 16.4	53.7 ± 10.3	45.3 ± 11.7
TOTAL	75.4	61.6	43.5	74.8	47.1

[1]Deer pellet samples consist of 20 pellets collected from 10, 3, 9, 10, and 3 pellet groups December, January, February, March, and April, respectively.

Table 21. Mean ($\overline{x}$) relative density $\pm$ a 95% confidence interval (CI) of discerned plant pellet samples[1] on the Calf Creek game range from December 1985 through April 1986. Calculations are based on data from 4 slides, with 20 fields of observations/slide.

	DEC	JAN	FEB	MAR	APR
	$\overline{x} \pm$ CI	$\overline{x} \pm$ CI	$\overline{x} \pm$ CI	$\overline{x} \pm$ CI	$\overline{x} \pm$ CI
GRASSES & GRASSLIKES					
Agropyron	---	0.6 ± 1.9	0.4 ± 1.3	---	0.5 ± 1.5
Carex	0.6 ± 2.1	3.8 ± 6.2	0.8 ± 1.4	10.2 ± 11.1	5.4 ± 6.7
Festuca	80.7 ± 5.9	62.8 ± 19.6	84.0 ± 11.3	55.9 ± 5.1	84.2 ± 13.9
Grass seed & glume	---	---	---	---	0.3 ± 1.1
Koeleria cristata	---	---	---	---	0.5 ± 1.5
Poa	0.6 ± 1.8	0.9 ± 3.0	0.4 ± 1.2	1.0 ± 1.8	0.5 ± 1.5
Stipa comata	---	3.8 ± 2.5	---	---	---
Unknown grass	---	---	---	1.1 ± 2.1	---
TOTAL	81.9	71.9	85.6	68.2	91.4
FORBS					
Artemisia frigida	---	1.3 ± 2.4	---	1.5 ± 2.8	---
Balsamorhiza sagittata	---	0.6 ± 1.9	---	---	---
Boraginaceae	---	0.5 + 1.5	---	0.6 ± 2.0	---
Centaurea maculosa	---	1.3 ± 2.4	---	---	---
Centaurea seed	9.7 ± 7.9	1.9 ± 6.0	5.2 ± 3.2	7.0 ± 6.3	---

Table 21 Continued.

	DEC $\bar{x} \pm CI$	JAN $\bar{x} \pm CI$	FEB $\bar{x} \pm CI$	MAR $\bar{x} \pm CI$	APR $\bar{x} \pm CI$
Flower[2]	1.4 ± 2.5	0.7 ± 2.3	---	---	---
Lupinus	1.2 ± 2.3	1.1 ± 2.1	1.2 ± 2.4	6.2 ± 4.9	0.3 ± 1.1
Seed	0.7 ± 2.2	0.6 ± 1.9	0.9 ± 2.7	0.6 ± 2.0	0.3 ± 1.1
Verbascum thapsus	0.5 ± 1.7	0.5 ± 1.7	---	---	---
TOTAL	13.5	8.5	7.3	15.9	0.6
SHRUBS					
Berberis repens	---	4.4 ± 5.9	---	4.7 ± 6.1	5.2 ± 4.4
Rubus	---	---	---	---	0.8 ± 1.5
Symphoricarpos albus	0.6 ± 1.8	---	---	---	---
TOTAL	0.6	4.4	0.0	4.7	6.0
TREES					
Pinus ponderosa	1.1 ± 2.0	---	2.6 ± 3.7	4.2 ± 2.7	---
Pseudotsuga menziesii	2.9 ± 5.5	15.2 ± 7.0	4.5 ± 4.6	7.0 ± 4.2	2.0 ± 1.3
TOTAL	4.0	15.2	7.1	11.2	2.0

[1]Elk pellet samples consist of 20 pellets collected from 10, 10, 10, 10, and 3 pellet groups for December, January, February, March, and April, respectively.

[2]Flower is probably that of *Centaurea*.

Tree use was prevalent during January, February, and March. Douglas-fir received more use than ponderosa pine during all months.

Forage Preference and Site Use

Threemile Deer. On open sites where ponderosa pine was present, deer showed a distinct preference for this plant (Table 22). On 1 feeding site when pine trees were not present, grass was preferred over knapweed. One mule deer pawed its way to the knapweed rosette leaves, but only 1 leaf tip was eaten.

Deer use of open sites during snow cover was very limited. Familiar travel routes through heavy or crusted snow were used to cross open areas but feeding on these sites was minimal.

During early spring, mule deer were seen grazing on open pastures adjacent to the range where plant growth initiated approximately 1 month earlier. The high coverage of knapweed litter on the range's open areas, as opposed to the adjacent cattle-grazed fields, may cause soil temperatures to rise more slowly, thereby delaying spring growth. Forb use was detected on this outlying area. No use of knapweed rosettes was noticed.

Mule deer were seen frequently feeding on edges during the winter. Edges were intermediate unique habitats or ecotones that existed between forested and open sites. Edges offered a wider variety of food items and usually had less snow cover than open areas, allowing deer to feed selectively. Again, when ponderosa pine was present, it was highly preferred (Table 23). Aster and grass were preferred food items on 2 sites when ponderosa pine was present. With weight preference, knapweed was preferred on 1

site over all other plants (ponderosa pine was not present). Knapweed had the highest bite preference on 6 feeding sites.

No use of knapweed rosette leaves was noticed on edge sites during the spring. Feeding on green grasses was observed but use seemed to be limited due to the presence of old litter encompassing new growth.

Forested areas also were heavily utilized feeding areas during the winter. Knapweed was found to be preferred on 2 feeding sites and preferred similarly with aster on another (Table 24). No spring use of knapweed rosettes was observed on forested sites.

On scattered pine sites, lupine and mullein were preferred most frequently over other plants (Table 25). Knapweed was well-utilized on 1 site (bite preference). Similiar winter use was detected between this area and open sites. Crusted snow was avoided and travel lanes were used. Observed spring use consisted of 1 bite from 1 rosette leaf.

No knapweed preference measurements were secured on knob sites because of time limitations and the intermingling of deer and elk tracks. Knapweed tops were consumed on these sites. No spring use of rosettes was noticed but bunchgrasses had been grazed. These open sites were used by both deer and elk during the winter and early spring for feeding and bedding sites.

<u>Threemile Elk</u>. On the 2 open sites measured, lupine was the preferred food item (Table 26). Knapweed was frequently eaten and had the highest bite preference on site 1. Ponderosa pine was not a preferred elk food on these sites as it was with mule

Table 22. Deer preference ratings for spotted knapweed on open sites[1] compared to other plants available on the same feeding site on the Threemile game range.

Feeding Site #	Date	Snow Depth(cm)	Species	Relative Avail.	Preference[2] Bites	Preference[2] Weight
1	1-27	0-2	knapweed	a[3]	0.11	0.01
			other forbs	t	0.00	0.00
			grass	wr	0.20	0.01
			ponderosa	c	2.40	1.60
2	1-28	0-15	knapweed	wr	3.87	0.21
			other forbs	c	1.20	1.54
			grass	wr	0.33	0.02
			ponderosa	c	8.80	5.74
3	1-28	0-15	knapweed	a	0.00	0.00
			lupine	c	0.40	0.20
			grass	wr	0.00	0.00
			ponderosa	c	4.40	4.00
4	2-14	23	knapweed	a	4.13	0.21
			grass	t	10.00	0.50
5	2-16	13	knapweed	a	1.20	0.06
			other forbs	t	0.00	0.00
			grass	c	0.00	0.00
			ponderosa	t	24.00	20.70

1/ Open sites are grasslands dominated by knapweed.

2/ The higher the number, the greater the preference.

3/ t=trace, c=common, wr=well represented, a=abundant

Table 23. Deer preference ratings for spotted knapweed on edge sites[1] compared to other plants available on the same feeding site on the Threemile game range.

Feeding Site #	Date	Snow Depth(cm)	Species	Relative Avail.	Preference[a] Bites	Preference[a] Weight
1	1-4	46	knapweed	vr[3]	2.27	0.11
			rose	vr	0.53	0.05
			other shrubs	c	0.00	0.00
			ponderosa	c	1.60	1.20
2	1-4	23	knapweed	vr	3.67	0.18
			aster	t	12.00	1.20
			ponderosa	c	0.00	0.00
3	1-28	0-18	knapweed	vr	0.67	0.03
			other forbs	c	0.00	0.00
			grass	c	8.00	0.80
			ponderosa	c	2.40	2.05
4	2-14	13	knapweed	t	0.00	0.00
			grass	vr	1.07	0.05
5	2-18	26	knapweed	c	0.40	0.02
			other forbs	t	0.00	0.00
			grass	t	0.00	0.00
			ponderosa	a	1.09	0.48
6	2-18	26	knapweed	vr	2.33	0.12
			other forbs	t	0.00	0.00
			grass	t	0.00	0.00
			ponderosa	a	1.94	1.11
7	2-19	21	knapweed	vr	9.27	0.50
			other forbs	t	0.00	0.00
			grass	t	2.00	0.10
			shrubs	t	0.00	0.00
			ponderosa	vr	8.87	5.09
8	2-19	13	knapweed	vr	0.80	0.04
			other forbs	t	0.00	0.00
			grass	t	0.00	0.00
			ponderosa	c	14.00	8.07
9	2-19	21	knapweed	vr	10.00	0.51
			other forbs	t	0.00	0.00
			grass	c	0.80	0.04
			serviceberry	c	3.60	0.36

Table 23 Continued.

Feeding Site #	Date	Snow Depth(cm)	Species	Relative Avail.	Preference[2] Bites	Preference[2] Weight
10	2-19	21	knapweed	c[3]	46.80	2.38
			other forbs	t	34.00	3.40
			grass	t	0.00	0.00
			shrubs	wr	0.00	0.00
			ponderosa	c	7.60	6.06
			Douglas-fir	t	2.00	0.40
11	2-19	21	knapweed	c	6.40	0.32
			other forbs	t	4.00	0.40
			grass	t	0.00	0.00
			serviceberry	c	4.40	0.44
			ponderosa	t	38.00	14.74
12	2-21	5-8	knapweed	t	26.00	1.50
			other forbs	t	4.00	0.40
			pinegrass	t	2.00	0.10
			rose	c	20.80	2.08
			snowberry	wr	0.27	0.01
13	3-13	8	knapweed	wr	1.95	0.10
			aster	c	13.60	1.36
			lupine	c	12.80	4.86
			grass	t	2.00	0.10
			kinnikinnik	t	24.00	2.40
			serviceberry	t	2.00	0.20
			ponderosa	t	40.00	21.40

1/ Edge sites are ecotones.

2/ The higher the number, the greater the preference.

3/ t=trace, c=common, wr=well represented, a=abundant

deer. Winter use of open study sites was very minimal and no spring use of these sites by elk was noticed.

Knapweed was well-utilized on the forested site, but weight preference was for lupine (Table 26). In spring, green grass and thistles in forested ravines were grazed by elk.

Lupine was preferred on a volume basis on most scattered pine sites (Table 27) and knapweed was preferred on a frequency basis. Ponderosa pine was rarely consumed. Elk bedded and fed in scattered pine sites and pawed for grasses there. Three orchard grass plants were grazed by elk on these sites in the spring. No use of knapweed was noticed.

Calf Creek Deer. Knapweed preference by deer was measured on 1 edge site (Table 28). Ponderosa pine had highest weight preference and knapweed had highest bite preference. Winter use of the study section of the range by deer was very minimal. Deer concentrated by ravines and rocky outcrops near ravines where snow cover was absent or minimal. During spring, no use of knapweed rosettes by deer was noticed. Spring use of shrubs and alfalfa was observed.

Calf Creek Elk. Preference for knapweed by elk was measured on 4 sites (Table 29). Grass was preferred on the edge site. In an open area, rose was preferred (weight) over knapweed, but knapweed was well-utilized. In the sagebrush area, knapweed was the most frequently eaten forb and had highest bite preference, but other forbs were given weight preference. On the forested site, knapweed had highest bite preference and thistles were highest in weight preference.

Table 24. Deer preference ratings for spotted knapweed on forested sites[1] compared to other plants available on the same feeding site on the Threemile game range.

Feeding Site #	Date	Snow Depth(cm)	Species	Relative Avail.	Preference[2] Bites	Preference[2] Weight
1	1-4	15	knapweed	c[3]	4.00	0.30
			aster	c	10.00	1.00
			grass	c	1.20	0.06
			snowberry	wr	0.00	0.00
2	2-16	18	knapweed	t	0.00	0.00
			other forbs	t	0.00	0.00
			grass	t	0.00	0.00
			shrubs	a	1.23	0.12
3	2-18	18	knapweed	t	12.00	6.00
			other forbs	t	0.00	0.00
			grass	t	0.00	0.00
			ponderosa	wr	0.80	0.46
4	2-18	18	knapweed	t	12.00	0.60
			aster	t	10.00	1.00
			grass	t	0.00	0.00
			snowberry	c	0.00	0.00
5	2-18	18	knapweed	c	20.80	1.14
			other forbs	c	9.60	0.96
			grass	c	0.00	0.00
6	2-21	8	knapweed	t	2.00	0.10
			lupine	t	4.00	2.50
			other forbs	t	2.00	0.40
			grass	t	0.00	0.00
			chokecherry	c	3.20	0.32
			oregongrape	c	36.00	11.88
			rose	c	1.60	0.16
			serviceberry	c	0.00	0.00
			snowberry	c	0.00	0.00

1/ Forested sites are areas with a tree overstory.

2/ The higher the number, the greater the preference.

3/ t=trace, c=common, wr=well represented, a=abundant

Table 25. Deer preference ratings for spotted knapweed on scattered pine sites[1] compared to other plants available on the same feeding site on the Threemile game range.

Feeding Site #	Date	Snow Depth(cm)	Species	Relative Avail.	Preference[2] Bites	Preference[2] Weight
1	1-4	31-46	knapweed	c[3]	0.00	0.00
			lupine	t	10.00	8.00
			grass	t	0.00	0.00
			ponderosa	c	2.00	6.84
2	2-18	26	knapweed	vr	0.93	0.05
			lupine	t	2.00	1.90
			mullein	t	2.00	1.60
			grass	t	0.00	0.00
			ponderosa	c	0.80	1.50
3	2-18	26	knapweed	vr	4.53	0.23
			mullein	t	2.00	1.60
			grass	t	0.00	0.00
			ponderosa	vr	0.27	0.11
4	2-18	26	knapweed	t	0.56	0.03
			other forbs	t	0.00	0.00
			grass	t	2.00	0.10
			ponderosa	vr	0.40	0.27

1/ Scattered pine sites are open sites with an overstory of ponderosa pine less than 3.0 m tall.

2/ The higher the number, the greater the preference.

3/ t=trace, c=common, vr=well represented, a=abundant

Table 26. Elk preference ratings for spotted knapweed on open and forested sites[1] compared to other plants available on the same feeding site on the Threemile game range.

Feeding Site #	Date	Snow Depth(cm)	Species	Relative Avail.[3]	Preference[2] Bites	Preference[2] Weight
1 (Open)	1-12	31	knapweed	wr	4.87	0.24
			lupine	t	2.00	1.20
			grass	t	4.00	0.20
			ponderosa	c	0.00	0.00
2 (Open)	2-16	18-31	knapweed	a	3.84	0.19
			lupine	t	12.00	8.10
			grass	t	0.00	0.00
			ponderosa	t	6.00	4.72
3 (Forest)	2-16	31	knapweed	c	23.60	1.32
			lupine	t	8.00	7.65
			grass	t	4.00	0.20
			shrubs	wr	3.53	0.53

1/ Open sites are grasslands dominated by spotted knapweed and forested sites are areas with a tree overstory.

2/ The higher the number, the greater the preference.

3/ t=trace, c=common, wr=well represented, a=abundant

Table 27. Elk preference ratings for spotted knapweed on scattered pine sites[1] compared to other plants available on the same feeding site on the Threemile game range.

Feeding Site #	Date	Snow Depth(cm)	Species	Relative Avail.	Preference[2] Bites	Preference[2] Weight
1	2-14	23	knapweed	vr[3]	16.60	0.83
			lupine	t	20.00	5.40
			grass	t	0.00	0.00
			ponderosa	t	2.00	1.50
2	2-14	23	knapweed	vr	5.27	0.28
			lupine	t	20.00	5.40
			salsify	c	18.00	0.90
			grass	vr	0.53	0.03
			ponderosa	c	0.00	0.00
3	2-16	21-31	knapweed	vr	10.93	0.55
			other forbs	t	0.00	0.00
			grass	t	6.00	4.10
			ponderosa	c	0.00	0.00
4	2-21	31	knapweed	c	21.60	1.10
			lupine	t	18.00	6.40
			grass	t	2.00	0.10
			ponderosa	vr	0.00	0.00

1/ Scattered pine sites are open sites with an overstory of ponderosa pine less than 3.0 m tall.

2/ The higher the number, the greater the preference.

3/ t=trace, c=common, vr=well represented, a=abundant

Table 28. Deer preference rating for spotted knapweed on an edge site[1] compared to other plants available on the same feeding site on the Calf Creek game range.

Feeding Site #	Date	Snow Depth(cm)	Species	Relative Avail.	Preference[2] Bites	Preference[2] Weight
1	1-10	15	knapweed	vr[3]	9.93	0.50
			other forbs	c	0.00	0.00
			grass	c	1.60	0.08
			snowberry	c	0.00	0.00
			rose	c	0.40	0.04
			ponderosa	t	4.00	3.00

1/ An edge site is an ecotone.

2/ The higher the number, the greater the preference.

3/ t=trace, c=common, vr=well represented, a=abundant

Table 29. Elk preference ratings for spotted knapweed on various sites[1] compared to other plants available on the same feeding site on the Calf Creek game range.

Feeding Site #	Date	Snow Depth(cm)	Species	Relative Avail.	Preference[2] Bites	Preference[2] Weight
1 (edge)	1-21	3	knapweed	wr[3]	7.40	0.37
			salsify	c	6.80	0.34
			grass	c	10.00	0.50
			big sagebrush	wr	0.00	0.00
			ponderosa	c	0.00	0.00
2 (open)	2-22	26	knapweed	wr	9.40	0.48
			grass	t	0.00	0.00
			big sagebrush	t	0.00	0.00
			rose	t	10.00	1.00
			ponderosa	t	0.00	0.00
3 (sage)	2-22	26	knapweed	wr	25.33	1.29
			other forbs	t	14.00	1.70
			grass	c	0.80	0.04
			big sagebrush	a	0.03	0.00
			ponderosa	t	0.00	0.00
4 (forest)	2-22	46	knapweed	t	12.00	0.60
			thistle	c	8.80	4.40
			grass	t	2.00	0.10
			shrubs	wr	0.07	0.01
			ponderosa	wr	0.13	0.04

1/ An edge site is an ecotone; an open site is a grassland dominated by spotted knapweed; a sage site is an open site with an overstory of big sagebrush; and a forested site is an area with a tree overstory.

2/ The higher the number, the greater the preference.

3/ t=trace, c=common, wr=well represented, a=abundant

Areas with a scattering of trees close to forests and ravine edges received the most use on the study area by elk during the winter. Elk grazed on open south slopes in winter and early spring. Elk tracks were followed in early spring within the study area and use of green grass and mineral licks was observed.

Discussion

Winter is the most stressful time of the year for wild ungulates. Most forage is nutrient poor during this time. Since cervids spend approximately half of each day foraging (Hanley 1982), with time increasing as forage quality and/ or quantity decreases (Trudell and White 1981), a high energy cost is associated with this activity. Therefore, it is important for these animals to chose, and be able to chose, those plants that meet their protein and energy needs.

The past use of the bunchgrass and shrub habitat types on the Threemile and Calf Creek game ranges has resulted in their present poor range condition. Spotted knapweed has invaded these sites and has replaced native plants.

Chemical analyses of the upper stems and dried flowers of knapweed reveal this plant part is nutritious throughout the winter. These tops have a relatively high percent crude protein compared to grasses. This protein source, in association with a high fiber and low lignin content, should provide the herbivore with a digestible forage. Utilization of knapweed by herbivores seems to be restricted to the flower tops because of cnicin concentrations in the leaves. Therefore, only a small portion on

the plant is being consumed by elk and deer. Several stems of knapweed were found lying on top of the snow on deer feeding sites. It seems deer were trying to eat these stems but cnicin concentrations in the leaves were distracting them.

Food habit studies using the bite method can over- or under-estimate the percent use of a plant as forage since different volumes of plants are consumed. The percent utilization of knapweed growing in open areas can easily by over-estimated because the tops are brittle and easily broken. Pellet or rumen analyses indicate a plant's use as a forage. The main weakness of these analyses is that easily digested plants may not be observed in samples and subsequently recorded as part of an animal's diet.

Forage preference measurements have not been previously performed under natural conditions. Preference ratings derived from forage use measurements using a weight method estimates the percent forage use of a plant more accurately than the alternative bite method because different volumes from plant species are consumed. Ocular availability measurements of cover percentage groups above snowline is necessary to obtain data in a limited amount of time. Consistent use of the median numbers from cover groups in calculating preference ratings may also reduce errors that may otherwise occur if trying to occularly measure an actual cover percentage.

Obtaining use and availability data by tracking animals in the snow is often the only way to record information about a certain species of animal. Problems that can be encountered when

collecting preference data are: a difference between recent and older bites cannot always be detected; plant availability can change quickly; use measurements can be biased on feeding sites with snow and bare ground coverage since bites are harder to determine where there is no snow; and there needs to be a fresh snow cover each time measurements are taken.

The winter of 1985-86 was mild. Monthly snow precipitation was low, excluding February, and temperatures throughout most of the winter were higher than normal. Few deer and elk used the study areas of the game ranges. The largest mule deer herd observed on the Threemile range consisted of approximately 20 animals. Seventeen elk were observed on 14 February. Groups of less than 10 mule deer were seen on the Calf Creek range. Four white-tailed deer were observed in April. The largest elk herd, estimated from tracks and beds, was 12 animals. Four elk were seen in April.

Deer and elk winter use of knapweed-dominated open and sagebrush areas was minimal. Feeding and bedding on these sites was observed in January during a clear, cold, snowy period. Deer and elk pawed for forbs and grasses on these sites. Feeding was minimal, seemingly due to a lack of preferred forage. These areas were not important feeding sites but are used in conjunction with other habitat requirements, such as bed sites for obtaining radiational warmth.

Hakin (1975) measured range condition on 6 sites on the Threemile game range and evaluated relative winter and spring use by elk and deer by counting winter and spring pellet groups on

these sites. The sites sampled are listed in order of decreasing animal use: bluebunch wheatgrass, bluebunch wheatgrass-columbia needlegrass (Stipa columbiana), yarrow, crested wheatgrass (Agropyron cristatum)-alfalfa, crested wheatgrass, and knapweeed. The bluebunch wheatgrass site had highest grass production and over 2000 pellet groups per acre; 1,575 pellet groups were elk and 635 pellet groups were deer. The knapweed site had only 43 pellet groups per acre; 35 were from elk and 8 from deer. Hakin's study strongly suggests an avoidance by deer and elk of knapweed-dominated areas as compared to other more productive sites.

Deer and elk use of the Calf Creek game range is influenced by the presence of a 8907 ha private sanctuary called the Stock Farm. This area is closed to hunting and elk and deer move onto this area in the fall and remain during the winter. The Stock Farm provides 5668 ha of good foothill winter range for these animals (Firebaugh, pers. comm.). State spring flight records (Firebaugh, 1986) for 1986 recorded 727 elk sightings between Willow Creek (north of the range) and Skalkaho Creek (south of the range). Ninety-five percent or 691 elk were sighted on the Stock Farm.

Closing the Calf Creek range to vehicular use before the hunting season may attract more elk and mule deer onto the range. However, the poor condition of much of the range cannot support many animals.

Deer and elk pellet samples are believed to be representative of mule deer and elk ranging in and near the game

ranges since animals moved freely in and out of the study areas and knapweed is found throughout both ranges. The dominant deer winter forage on both ranges consisted of oregongrape, ponderosa pine, and Douglas-fir. These evergreen plants seem very palatable and highly preferred by mule deer. The higher consumption of ponderosa pine to Douglas-fir by Threemile deer and vice versa for Calf Creek deer is probably influenced by these trees different availability where the deer are ranging. Deer consumption of deciduous browse was observed to be greatest after a heavy snowfall. Deciduous browse received little use in comparison to evergreen browse during the winter, and is probably lower in digestibility. Compared to other available forage, the high consumption of evergreen browse may be influenced by the palatability of these plants, the high protein content of green forage and browse in general, a lower energy cost associated with consuming large bites from these plants, and the low availability of more preferred forages.

Willow and Rubus were the only deciduous shrubs found in appreciable amounts in deer pellets. Geis (1954), Hungerford (1952), and Boll (1958) found willow to be the most preferred deciduous shrub by elk. Willow consumption by deer in March may parallel initial sap rise in this shrub and corresponding deer preference for nutrient-rich forage. The high consumption of Rubus, also a wet-site plant, by deer on both ranges in April implies this shrub is also an early available nutrient source.

Pellet analyses prove that deer on both ranges consumed knapweed throughout the study period. Mean use was 4.6% and 6.9%

on the Threemile and Calf Creek ranges, respectively. Percent use of knapweed seemed to be positively correlated to its availability since the highest consumption was observed on sites where it was abundant. However, knapweed had highest preference ratings in forested sites with either trace or common availability cover as compared to other measured sites. It was not brittle nor was it fully-developed and dry. These plants may have a higher protein content than those sampled from openings in the forest. Deer may be selecting these plants because of a high protein content and are not negatively influenced by the higher lignin content associated with forest plants. Swift (1948), Longhurst et. al. (1968), Healy (1971), and Willms and McLean (1978) found that deer select the more nutritious forages when they are available. Percent use of these knapweed plants does not seem very important because of their low availability.

Knapweed was found to have a higher preference rating than categories of grasses, forbs, and deciduous shrubs on some feeding sites. Grasses on these sites were mainly small patches of smooth brome (Bromus inermis) or widely scattered bluegrass stems that had a similar or lower availability coverage than knapweed. Forbs were small in size and also widely scattered with a similar or lower availability coverage than knapweed.

The higher preference rating for knapweed to those of grasses and forbs seems to be influenced by the higher availability of knapweed. Most measured feeding sites had substantial snow cover. However, this lower coverage alone cannot explain knapweed's preference since lupine also had lower

coverage than knapweed but was preferred over it. The unpreferred forbs and grasses on these measured sites are also dry like knapweed but are probably lower in nutrients. Many forbs and grasses on these poor-condition sites are characteristic of low-quality forage.

Grasses were found in extremely low quantities in deer pellets. It seems grasses were not a preferred deer forage on these ranges either due to low availability because of snow cover and/or low nutrient quality of grasses available to deer where they are ranging.

Some forbs, such as lupine and balsamroot, were highly preferred deer forages. Their high and low usage during the study months indicates that their percent use is dramatically influenced by snow cover. Knapweed, however, is almost always available. Use of this plant may be lowest during periods of heavy snowfall when deer move to the forest cover where this weed is found in least abundance.

The higher preference rating for knapweed over deciduous shrubs does not seem to be influenced by availability. The shrub least preferred on measured sites was snowberry. The stems of this shrub are thin and dry, unlike most other shrubs. Pellet analyses indicate willow and thimbleberry were the most preferred deciduous shrubs during the study.

Because few elk preference data were obtained, limited inferences can be stated concerning a knapweed preference over other plant species. However, the higher elk preference of knapweed to forbs and grasses on some measured feeding sites may

also be explained by a lower or relatively equal availability of lower-quality grasses and forbs.

The high consumption of fescue by elk on both ranges is not suprising, especially since the winter was mild. Threemile elk had a more versatile diet than Calf Creek elk, probably because of a lower availability of the highly preferred fescue. Consumption of fescue by elk was highest in April on both ranges and no utilization of knapweed was observed or documented during the spring.

The higher percent use of Douglas-fir as compared to ponderosa pine may also be related to a higher availability where they are ranging. Ponderosa pine was not a preferred forage on any elk feeding site. Consumption of shrubs by elk was not high but species utilized were also those used by deer. Therefore, a potential competition exists between these animals for these shrubs.

Conclusions

On the Bitterrroot game ranges, spotted knapweed seemed to be consumed by elk and deer predominately as a response to its high availability. Generally, knapweed was preferred over less available and/or less desirable plants. Percent use was low considering its high availability and because only the tops were utilized as forage by deer and elk.

Positive attributes of knapweed are: it is a tall forb that persists throughout winter and is available as forage for elk and deer; the flower tops provide protein and energy for herbivores;

and elk and mule deer are eating these tops in the winter (with deer use continuing through spring). The negative aspects of knapweed are more monumental. This weed's presence has drastically reduced grass and forb production of more desirable forage plants which has resulted in extremely low use of these sites for foraging. The litter that has accumulated as a result of this low site use is also causing spring growth of plants to be delayed.

Elk seem more negatively affected than mule deer by the presence of knapweed. Elk diets are usually not as versatile and are dominated, whenever possible, by grasses, especially fescues. These grasses are being replaced by knapweed.

Removal of this weed by sheep grazing could cause serious erosion and political problems and would not get rid of the knapweed seeds. Herbicides would have to be used to kill the seedlings. Replanting with native bunchgrasses may require continuous herbicidal spraying since a bare ground component, in which knapweed can reseed, is typical of bunchgrass ranges. Present biological controls are not effective at reducing or stopping the spread of knapweed. The only alternatives are to take no action or to spray and replant with more desirable rhizomatous grasses. Proper summer and fall cattle grazing of these grasses would prevent the build-up of grass litter.

CHAPTER V

ALLELOPATHIC EFFECTS OF SPOTTED KNAPWEED

Abstract: Treatments using the top-growth of knapweed plants did not have a phytotoxic effect on germination or growth of lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*) or western larch (*Larix occidentalis*), or to photosynthesis or growth of ponderosa pine (*Pinus ponderosa*) seedlings. However, phytotoxicity to germination and survival of western larch, lodgepole pine, and ponderosa pine was observed when only leaf material of knapweed was applied. Addition of any type of organic matter increased mortality, probably by increasing the energy source to soil microorganisms.

Phytotoxic effects of knapweed leaves to germination and survival were more evident for ponderosa pine when the growth medium was sand than when the growth medium was a vermiculite mix. The more evident phytotoxicity caused by knapweed leaves applied to the sand medium was related to two factors: (1) Within treatment variation was much greater in seedlings grown in a vermiculite soil mix because of "damping off", and (2) Toxicity was probably decreased in the vermiculite mix because of absorption of the toxic compound to soil particles and greater degradation of cnicin.

Ponderosa pine survival was increased where knapweed was controlled. Increased survival was probably related to a

decrease in competition for water and was not believed to be related to allelopathy since knapweed had been growing on the site and was still present in the soil.

The large amount of knapweed leaves necessary to cause a significant decrease in germination and survival of ponderosa pine, western larch, and lodgepole pine suggests that there are other factors leading to the success of knapweed on clearcuts and grassland sites. From our research and other studies we believe that knapweed's success is related to its ability to compete for resources in short supply. Once knapweed is controlled there is a rapid increase in growth of existing plants because of additional resources. The increase in growth is about equal to the amount of knapweed controlled.

Knapweed begins growth very early in the spring which increases its ability to compete for resources. When knapweed was introduced into North America natural enemies such as herbivores and diseases were left behind in Europe. It is very likely that the ability of knapweed to compete for water and nutrients is greatly increased because of its limited utilization by insects, mammals and possibly from soil fauna when compared to the surrounding vegetation. Therefore, it is our belief that the introduction of knapweed has changed the competitive balance of many sites in western Montana. This competitive imbalance has shifted these sites to knapweed-dominated sites.

Introduction

The success of knapweed in western Montana has often been attributed to allelopathy. Allelopathy is defined as any direct or indirect harmful effect by one plant on another through the production of chemical compounds that escape into the environment (Rice 1974).

There is laboratory evidence and circumstantial evidence that the success of spotted knapweed in western Montana may be associated with allelopathy. Our objective was to determine if spotted knapweed plant material was functioning as an inhibitor to germination, survival and growth of some western Montana timber species under greenhouse and field conditions. We developed four different experiments to detect possible allelopathic effects. Each of these experiments will be presented as separate sections.

Literature Review

Several researchers have confirmed the presence of inhibitory substance in one or more species of Centaurea (Fletcher and Renney 1963, Maddox 1982, Muir and Majak 1983, Locken and Kelsey 1987) and the tendency of knapweed to form dense patches was postulated as an allelopathic effect by Fletcher and Renney (1963) and Maddox (1982). Cavillito and Bailey (1949) have also reported that spotted knapweed extracts had antibacterial activity.

Fletcher and Renney (1963) found that the growth of tomato and barley was inhibited in soils naturally infested with

knapweed or in soils artificially infested with powdered knapweed residues. The leaves contained a higher proportion of the toxic material than did other plant parts, and the leaves of Russian knapweed (Centaurea repens L.) were more inhibitory than those of diffuse knapweed (C. diffusa) and spotted knapweed (C. maculosa). Spotted knapweed leaves had the least inhibitory effects in their experiment. The inhibitory effects of the knapweeds on germinating plants of lettuce and barley were greater on root growth than on top growth.

Spotted knapweed seedlings exhibit vigorous growth (Lacey et al. 1986). Maximum root growth occurs during the rosette state (Watson and Renney 1974) which allows for early spring growth when temperature and moisture conditions are favorable. This early spring growth makes knapweed a strong competitor for soil moisture and nutrients.

Locken and Kelsey (1987) isolated a sesquiterpene lactone, cnicin, from the glandular trichomes on the epidermal surfaces of spotted knapweed which was identified as a phytotoxic compound. The highest concentration of the cnicin occurred in leaf tissues, with low quantities in the inflorescence branches, stems and heads. There was no cnicin in the roots. Concentrations in the rosette leaves ranged from about 0.5% dry weight in the spring, up to 1.0% after flowering in the late summer. Under laboratory conditions cnicin was phytotoxic to all plant species bioassayed including lettuce, crested wheatgrass (Agropyron desertorum), rough fescue (Festuca scabrella), bluebunch wheatgrass (Agropyron spicatum), western larch, lodgepole pine and spotted knapweed

itself. Cnicin inhibited the germination of all species, except lodgepole pine and spotted knapweed, although it was not a strong germination inhibitor. Locken and Kelsey (1987) isolated only trace quantities of cnicin from the soil on their study site and hypothesized that cnicin was probably not acting as a strong inhibitor under field conditions.

Muir and Majak (1983) found that root and aerial tissues of diffuse knapweed contained an inhibitor to germination and growth of ryegrass (Lolium multiflorum). Cnicin was isolated from leaves but was rejected as the major inhibitor. The inhibitor was not isolated.

Experiment 1: Influence of Spotted Knapweed on Germination, Growth and Survival of Lodgepole Pine, Douglas-fir and Western Larch.

Methods

Potential allelopathic effects of spotted knapweed litter were tested on lodgepole pine, Douglas-fir and western larch grown in four cu. in. Ray Leach containers at the Montana Department of State Lands greenhouse. The diameter of the tubes was 2.54 cm and the growth medium was added to about 1 cm from the top of the tube. Liquid capacity of the tubes was 55 milliliters. Treatments consisted of six levels of knapweed plant material, six identical levels of elk sedge (Carex geyeri) plant material and a control replicated 5 times in a vermiculite mix and a sand medium. The two growth mediums were used to

determine if knapweed added to an inert material such as sand would cause greater inhibitory effects in the tree seedlings. The six levels of added plant material were 0.057 g, 0.1138 g, 0.2274 g, 0.4546 g, 0.9089 g and 1.8174 g. These six levels of spotted knapweed and elk sedge material used as treatments were equivalent to adding 1,000 lbs./ac, 2,000 lbs./ac, 4,000 lbs./ac., 8,000 lbs./ac., 16,000 lbs./ac, and 32,000 lbs./ac., respectively, of plant material on an area basis. For the first three levels the plant material was applied to the surface of the vermiculite or sand and gently mixed into the surface of the growth medium. For the other treatments the plant material was mixed with about the top 50% of the growth medium in the container. The tree seeds were then planted in all containers and were in contact with the plant material used as treatments.

The knapweed plant material consisted of current year's top growth (leaves, stems and flowers) of knapweed plants collected during August 1985. Immediately after collection the knapweed was placed in a convection oven and dried for 5 days at 65°C. The knapweed material was mixed and ground with a Wiley mill to pass through a 2 mm screen.

The elk sedge plant material consited of elk sedge leaves collected during the summer of 1985. This plant material had also been dried in a convection oven after collection and ground with a Wiley mill and stored in air-tight containers.

On March 4, 1986 we planted 3 seeds/container for western larch and lodgepole pine and 6 seeds/container for Douglas-fir. Each treatment for each species and growth medium was replicated

five times. Growth conditions in the greenhouse are shown in Table 30.

Table 30. Growing regime of tree seedlings at the Department of State Land greenhouse.

	Growth Stage	
	Germination	Juvenile Growth
Day Temperature	65-80 (70)	75-90 (75)
Night Temperature	65-80 (65)	55-70 (60)
Relative Humidity	70-100 (80)	70 (<70)
Supplemental Light	none	24 hr. photoperiod
Water	1-3 light waterings per day to keep surface moist.	Watered when needed. No H_2O stress.
Fertilizer (N,P,K)	None	9/45/15

Benlate fungicide was applied to control damping off on 3/25/86.

Germination was measured by counting seedlings on March 19, April 1, April 14, and April 24. On April 24 all but one seedling were removed from each container to remove any intraspecific competition. Heights of seedlings were measured from the top of the container on April 7, April 24, May 20, June 3, July 23, and August 20. Dead seedlings were not included in height measurements. Mortality (%) was recorded in 1986 on April 5, April 20, June 23, and October 3. We also measured mortality on April 29, 1987 after seedlings had gone through winter dormancy and had become active.

Results and Discussion

There were no consistent effects of any treatments on

seedling germination of lodgepole pine, western larch or Douglas-fir (Tables 31-36). Significant differences in germination of seedlings were documented for lodgepole pine grown in sand on March 19 (Table 31), western larch grown in sand for April 7, April 14, and April 24 (Table 32), and western larch grown in soil on March 19 (Table 35). However, differences in treatments for these dates were not believed to be caused by a phytotoxic effect. For all dates and treatments there were no apparent signs of phytotoxicity as the rate of spotted knapweed increased.

There were no apparent visual signs of damage caused to the germinated seedlings of any species by any treatment. Differences in the average height (cm) were noted for some dates but the differences in height growth were not consistent as treatments increased (Tables 37-42). Mortality (%) was high for some treatments but again there was no consistent increase in mortality as treatment levels increased (Tables 43-48).

From this experiment we could find no phytotoxicity associated with the added knapweed material. Locken and Kelsey (1986) stated that cnicin was the phytotoxic substance in knapweed and that cnicin was concentrated in the epidermal glands of the leaves. Since we used whole plant material the amount of cnicin may not have been great enough to cause symptoms of phytotoxicity. Also, Locken and Kelsey (1986) stated that the cnicin apparently was degraded in the soil environment which could have reduced any phytotoxicity associated with the knapweed.

Table 31. Influence of additions of knapweed (<u>Centaurea maculosa</u>) and elk sedge (<u>Carex geyeri</u>) plant material on germination of lodgepole pine (<u>Pinus contorta</u>) grown in a sand medium.

Treatment (lb/ac)[1]	March 19	April 1	April 7	April 14	April 24
Knapweed					
1,000	27a[2]	67a	67a	67a	73a
2,000	20a	80a	80a	80a	80a
4,000	47b	67a	67a	67a	67a
8,000	20a	47a	47a	47a	47a
16,000	13a	67a	67a	67a	67a
32,000	60bc	87a	80a	67a	73a
Elk Sedge					
1,000	20a	73a	73a	73a	73a
2,000	80c	67a	60a	60a	60a
4,000	27a	60a	53a	60a	60a
8,000	67bc	80a	80a	80a	87a
16,000	53b	80a	80a	80a	80a
32,000	60bc	87a	87a	87a	80a
Control	28a	72a	72a	72a	61a

[1]Treatments are presented as equivalent to lb/ac.
[2]Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 32. Influence of additions of knapweed (<u>Centaurea maculosa</u>) and elk sedge (<u>Carex geyeri</u>) plant material on germination of western larch (<u>Larix occidentalis</u>) grown in a sand medium.

Treatment (lb/ac)[1]	March 19	April 1	April 7	April 14	April 24
Knapweed					
1,000	60a[2]	73a	73b	87b	80b
2,000	80a	87a	93b	93b	93b
4,000	60a	80a	80b	80b	93b
8,000	47a	87a	80b	87b	87b
16,000	73a	73a	73b	73b	73b
32,000	73a	73a	80b	80b	67b
Elk Sedge					
1,000	53a	73a	73b	73b	67ab
2,000	67a	73a	73b	73b	73b
4,000	40a	53a	33a	40a	40a
8,000	60a	87a	87b	87b	87b
16,000	67a	73a	80b	73b	80b
32,000	73a	80a	80b	80b	80b
Control	44a	72a	72b	61ab	61ab

[1]Treatments are presented as equivalent to lb/ac.
[2]Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 33. Influence of additions of knapweed (*Centaurea maculosa*) and elk sedge (*Carex geyeri*) plant material on germination of Douglas-fir (*Pseudotsuga menziesii*) grown in a sand medium.

Treatment (lb/ac)[1]	March 19	April 1	April 7	April 14	April 24
Knapweed					
1,000	17[a]	17	17	17	17
2,000	23	27	27	27	27
4,000	30	30	30	30	30
8,000	27	27	27	27	30
16,000	20	20	20	20	20
32,000	40	40	40	40	40
Elk Sedge					
1,000	23	37	40	37	40
2,000	13	30	30	30	20
4,000	23	27	27	27	27
8,000	33	33	33	33	33
16,000	33	33	33	33	33
32,000	43	43	43	43	43
Control	28	28	22	22	22

[1] Treatments are presented as equivalent to lb/ac.
[a] Means are not different at the 0.05 level of probability.

Table 34. Influence of additions of knapweed (*Centaurea maculosa*) and elk sedge (*Carex geyeri*) plant material on germination of lodgepole pine (*Pinus contorta*) grown in a vermiculite mix.

Treatment (lb/ac)[1]	March 19	April 1	April 7	April 14	April 24
Knapweed					
1,000	27[a]	53	53	47	47
2,000	13	47	53	53	53
4,000	27	73	73	67	67
8,000	13	73	73	73	73
16,000	20	53	47	47	47
32,000	13	67	33	40	33
Elk Sedge					
1,000	27	67	67	67	73
2,000	27	53	47	47	47
4,000	27	33	60	53	60
8,000	0	33	33	33	33
16,000	27	53	60	60	67
32,000	7	80	87	93	93
Control	44	78	78	78	78

[1] Treatments are presented as equivalent to lb/ac.
[a] Means are not different at the 0.05 level of probability.

Table 35. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on germination of western larch (Larix occidentalis) grown in a vermiculite mix.

Treatment (lb/ac)[1]	March 19	April 1	April 7	April 14	April 24
Knapweed					
1,000	27ab[2]	68a	68a	68a	68a
2,000	40b	73a	73a	73a	73a
4,000	7a	27a	27a	27a	27a
8,000	33ab	53a	53a	53a	53a
16,000	7a	33a	33a	33a	33a
32,000	27ab	67a	60a	60a	60a
Elk Sedge					
1,000	27ab	53a	53a	53a	53a
2,000	73d	87a	87a	87a	87a
4,000	53cd	60a	60a	60a	60a
8,000	13ab	33a	33a	33a	33a
16,000	53cd	73a	73a	73a	73a
32,000	20ab	93a	40a	40a	40a
Control	61cd	67a	72a	67a	72a

[1] Treatments are presented as equivalent to lb/ac.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 36. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on germination of Douglas-fir (Pseudotsuga menziesii) grown in a vermiculite mix.

Treatment (lb/ac)[1]	March 19	April 1	April 7	April 14	April 24
Knapweed					
1,000	0[2]	3	3	3	3
2,000	0	3	3	3	3
4,000	7	20	20	20	20
8,000	7	20	20	20	20
16,000	7	17	17	17	17
32,000	0	7	7	7	7
Elk Sedge					
1,000	17	27	27	27	27
2,000	7	20	20	20	20
4,000	7	23	23	23	23
8,000	0	13	13	13	13
16,000	0	10	10	10	10
32,000	0	7	3	3	3
Control	19	33	31	31	31

[1] Treatments are presented as equivalent to lb/ac.
[2] Means are not different at the 0.05 level of probability.

Table 37. Influence of additions of knapweed (*Centaurea maculosa*) and elk sedge (*Carex geyeri*) plant material on height (cm) of lodgepole pine (*Pinus contorta*) grown in a sand medium.

Treatment (lb/ac)[1]	Apr 7	Apr 24	May 5	May 20	June 3	July 23	Aug 20
Knapweed							
1,000	2.3a[2]	3.6a	4.1bc	4.4d	4.9e	5.0cde	5.2cd
2,000	2.1a	3.5a	4.2c	3.8bcd	4.4cde	4.4bcd	4.3bc
4,000	2.0a	3.5a	3.5b	3.0bc	3.8bcd	4.3bcd	4.4bc
8,000	2.0a	3.4a	3.4b	3.4bc	4.3cde	4.4bcd	4.8bcd
16,000	2.2a	3.1a	2.2a	1.3a	2.0ab	2.7a	2.7a
32,000	2.2a	4.2a	3.3b	2.8bc	3.2ab	3.6a	3.3ab
Elk Sedge							
1,000	1.9a	3.6a	3.7b	3.3bcd	4.0cde	4.2bcd	4.5bc
2,000	2.3a	3.3a	3.6b	3.4bcd	3.5abc	4.3bcd	4.6bc
4,000	2.1a	3.3a	4.0bc	3.9c	4.4cde	5.0cde	5.4cd
8,000	2.1a	3.8a	4.4c	4.4d	5.3e	5.9e	6.2d
16,000	2.5a	3.8a	3.7b	3.8bcd	4.3cde	5.2de	5.5c
32,000	1.7a	1.4a	2.2a	2.7b	2.7ab	3.0ab	3.5ab
Control	2.0a	3.0a	3.0ab	2.8bc	3.0ab	3.6ab	3.3a

[1] Treatments are presented as equivalent to lb/ac.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 38. Influence of additions of knapweed (*Centaurea maculosa*) and elk sedge (*Carex geyeri*) plant material on height (cm) of western larch (*Larix occidentalis*) grown in a sand medium.

Treatment (lb/ac)[1]	Apr 7	Apr 24	May 5	May 20	June 3	July 23	Aug 20
Knapweed							
1,000	2.2a[2]	4.1abc	4.3abc	3.8ab	4.7[3]	4.7	5.2
2,000	2.2a	4.6abc	3.8ab	4.2ab	4.3	4.9	5.0
4,000	2.4a	4.9c	4.7abc	4.8abc	6.5	7.3	7.3
8,000	2.2a	5.3c	5.1bc	5.4abcd	6.0	0	0
16,000	2.3a	4.9c	4.6abc	6.2cd	6.0	7.1	7.2
32,000	2.3a	3.9ab	3.4a	4.8abc	6.0	0	0
Elk Sedge							
1,000	2.7a	4.9c	4.6abc	4.3abc	7.0	7.8	8.8
2,000	2.4a	5.0c	5.6c	7.4d	7.1	6.5	5.0
4,000	2.3a	3.4ab	4.7abc	5.8abcd	6.0	6.4	6.5
8,000	2.6a	4.8bc	4.8abc	6.0cd	7.0	7.5	7.3
16,000	2.2a	3.7ab	3.4a	3.5a	4.0	4.0	2.8
32,000	2.2a	3.3a	3.3a	4.0abc	4.9	6.8	6.7
Control	2.0a	3.4ab	4.3abc	3.8ab	4.6	5.2	4.3

[1] Treatments are presented as equivalent to lb/ac.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 39. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on height (cm) of Douglas-fir (Pseudotsuga menziesii) grown in a sand medium.

Treatment (lb/ac)[1]	Apr 7	Apr 24	May 5	May 20	June 3	July 23	Aug 20
Knapweed							
1,000	2.6c[2]	4.2a	4.2a	4.3c	4.7a	6.2b	6.5[3]
2,000	2.4bc	3.1a	3.3a	3.8bc	5.1a	6.7b	6.7
4,000	2.3abc	3.3a	3.1a	3.1abc	3.9a	4.7ab	5.1
8,000	2.5c	3.6a	3.5a	3.3abc	4.0a	4.7ab	5.1
16,000	2.4bc	3.0a	2.9a	2.5ab	3.1a	3.7a	3.5
32,000	2.0ab	3.4a	2.7a	2.4ab	3.7a	5.6ab	7.1
Elk Sedge							
1,000	2.3abc	3.2a	3.1a	3.0ab	3.6a	4.7ab	5.1
2,000	1.9a	2.5a	2.7a	2.9ab	3.5a	5.3ab	5.4
4,000	2.4bc	3.1a	3.4a	3.4abc	4.3a	5.8b	5.5
8,000	2.2abc	3.2a	3.6a	3.5abc	4.7a	6.1b	6.8
16,000	2.4bc	3.6a	3.5a	3.5abc	4.9a	6.7b	7.0
32,000	2.1abc	2.7a	3.0a	2.7ab	4.2a	5.9b	6.0
Control	1.9	3.0	2.3	2.3a	3.0a	3.4a	3.5

[1]Treatments are presented as equivalent to lb/ac.
[2]Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 40. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on height (cm) of lodgepole pine (Pinus contorta) grown in a vermiculite mix.

Treatment (lb/ac)[1]	Apr 7	Apr 24	May 5	May 20	June 3	July 23	Aug 20
Knapweed							
1,000	2.3a[2]	4.7d	5.8b	8.7d	7.9a	8.5a	8.8a
2,000	2.1a	3.8abcd	5.4b	7.4cd	8.1a	8.6a	8.9a
4,000	2.5a	4.1abcd	5.2b	7.7cd	8.5a	8.7a	9.1a
8,000	2.5a	4.5cd	5.7b	6.3bc	7.4a	7.8a	8.3a
16,000	2.3a	4.0abcd	5.3b	7.3bcd	9.3a	10.4a	10.8a
32,000	2.2a	3.2ab	4.8a	7.0bcd	8.8a	10.0a	10.4a
Elk Sedge							
1,000	2.2a	3.4abc	4.9a	7.0bcd	8.0a	8.7a	8.9a
2,000	2.6a	3.8abcd	5.0a	6.5bc	7.9a	8.4a	8.7a
4,000	2.6a	4.2bcd	5.2b	6.8bcd	8.6a	9.1a	9.3a
8,000	2.1a	3.7abcd	4.3a	5.3ab	7.2a	7.6a	8.0a
16,000	2.2a	3.8abcd	5.0a	6.4bc	7.9a	8.7a	9.0a
32,000	2.2a	2.9a	3.4a	4.0a	5.9a	7.9a	8.2a
Control	2.9a	4.8d	5.8b	6.3bc	7.6a	7.8a	7.9a

[1]Treatments are presented as equivalent to lb/ac.
[2]Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 41. Influence of additions of knapweed (*Centaurea maculosa*) and elk sedge (*Carex geyeri*) plant material on height (cm) of western larch (*Larix occidentalis*) grown in a vermiculite mix.

Treatment (lb/ac)[1]	Apr 7	Apr 24	May 5	May 20	June 3	July 23	Aug 20
Knapweed							
1,000	2.1[a]	3.6	4.4	5.3	6.5	7.7	7.8
2,000	3.1	4.5	5.1	6.3	7.1	8.2	8.4
4,000	3.0	4.7	4.8	6.8	8.0	10.3	10.5
8,000	2.8	4.3	4.8	6.9	7.7	9.5	9.5
16,000	2.3	3.8	4.7	8.0	9.0	13.5	13.5
32,000	2.3	3.8	4.8	7.0	9.8	12.1	12.2
Elk Sedge							
1,000	2.8	4.4	4.4	7.5	8.5	11.9	11.9
2,000	3.3	5.2	5.5	7.1	8.6	11.4	11.4
4,000	2.9	4.9	5.6	8.5	8.8	10.7	10.8
8,000	3.1	4.5	5.0	7.5	8.0	10.4	10.5
16,000	2.9	4.8	5.4	8.2	9.4	12.3	12.3
32,000	2.4	3.7	4.5	7.3	8.5	11.9	12.1
Control	2.9	4.7	6.2	7.3	8.6	9.6	10.8

[1] Treatments are presented as equivalent to lb/ac.
[a] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 42. Influence of additions of knapweed (*Centaurea maculosa*) and elk sedge (*Carex geyeri*) plant material on height (cm) of Douglas-fir (*Pseudotsuga menziesii*) grown in a vermiculite mix.

Treatment (lb/ac)[1]	Apr 7	Apr 24	May 5	May 20	June 3	July 23	Aug 20
Knapweed							
1,000	1.0[a]	2.0	3.0	3.5	4.5	4.2	4.2
2,000	2.5	4.0	4.0	4.5	6.0	7.8	8.2
4,000	2.3	3.3	3.0	3.3	4.5	5.7	6.1
8,000	2.5	3.3	3.3	3.0	4.3	5.6	6.1
16,000	2.1	3.0	3.5	4.3	4.2	7.6	7.9
32,000	1.7	2.8	2.7	3.3	4.0	6.3	6.6
Elk Sedge							
1,000	2.7	3.8	4.0	4.2	5.0	7.1	7.3
2,000	2.0	3.4	3.3	3.3	4.4	6.3	6.4
4,000	2.2	3.3	3.3	3.5	5.2	7.3	7.5
8,000	2.3	3.5	3.3	4.0	5.0	6.8	6.8
16,000	2.5	3.3	3.3	4.0	5.0	6.5	7.5
32,000	1.0	1.0	1.0	1.0	3.0	4.8	4.8
Control	2.4	3.7	3.8	3.7	5.2	6.7	6.9

[1] Treatments are presented as equivalent to lb/ac.
[a] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

and elk sedge (Carex geyeri) plant material on mortality (%) of lodgepole pine (Pinus contorta) grown in a sand medium.

Treatment (lb/ac)[1]	5/05/86	5/20/86	6/23/86	8/20/86	10/03/86	4/29/87
Knapweed						
1,000	0	0	20	20	20	60
2,000	0	0	60	60	60	80
4,000	0	0	0	0	0	40
8,000	20	20	60	60	60	80
16,000	0	20	20	20	20	100
32,000	20	20	40	40	40	80
Elk Sedge						
1,000	0	0	20	20	20	40
2,000	20	20	60	60	60	40
4,000	0	0	0	0	0	40
8,000	0	0	20	20	20	60
16,000	0	0	0	0	0	60
32,000	0	0	0	0	0	40
Control	20	20	50	50	50	80

1 Treatments are equivalent to pounds/acre on a surface area basis.

Table 44. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on mortality (%) of western larch (Larix occidentalis) grown in a sand medium.

Treatment (lb/ac)[1]	5/05/86	5/20/86	6/23/86	8/20/86	10/03/86	4/29/87
Knapweed						
1,000	0	0	60	60	60	60
2,000	0	0	60	60	60	60
4,000	0	0	80	80	80	80
8,000	0	0	100	100	100	100
16,000	0	0	40	40	40	40
32,000	0	0	100	100	100	100
Elk Sedge						
1,000	0	40	80	80	80	80
2,000	0	0	80	80	80	80
4,000	20	20	40	40	40	40
8,000	0	0	40	40	40	40
16,000	0	20	60	60	60	60
32,000	0	0	20	20	20	20
Control	0	0	50	50	50	50

1 Treatments are equivalent to pounds/acre on a surface area basis.

Table 45. Influence of additions of knapweed (<u>Centaurea maculosa</u>) and elk sedge (<u>Carex geyeri</u>) plant material on mortality (%) of Douglas-fir (<u>Pseudotsuga menziesii</u>) grown in a sand medium.

Treatment (lb/ac)[1]	5/05/86	5/20/86	6/23/86	8/20/86	10/03/86	4/29/87
Knapweed						
1,000	40	40	60	60	60	60
2,000	0	0	0	0	20	20
4,000	0	0	20	20	20	20
8,000	40	40	40	40	40	40
16,000	20	20	80	80	80	80
32,000	0	0	60	60	60	60
Elk Sedge						
1,000	0	0	20	20	20	20
2,000	0	0	20	20	20	20
4,000	20	20	80	80	80	80
8,000	0	0	20	20	20	40
16,000	20	20	20	20	20	60
32,000	0	0	0	0	0	20
Control	20	20	60	60	60	60

1 Treatments are equivalent to pounds/acre on a surface area basis.

Table 46. Influence of additions of knapweed (<u>Centaurea maculosa</u>) and elk sedge (<u>Carex geyeri</u>) plant material on mortality (%) of lodgepole pine (<u>Pinus contorta</u>) grown in a vermiculite mix.

Treatment (lb/ac)[1]	5/05/86	5/20/86	6/23/86	8/20/86	10/03/86	4/29/87
Knapweed						
1,000	20	20	20	20	20	20
2,000	0	0	0	0	0	80
4,000	20	20	20	20	20	80
8,000	20	20	20	20	20	80
16,000	40	40	40	40	40	80
32,000	40	40	40	40	40	80
Elk Sedge						
1,000	0	0	0	0	0	40
2,000	20	20	20	20	20	40
4,000	0	0	0	0	0	60
8,000	40	40	40	40	40	100
16,000	0	0	0	0	0	0
32,000	0	0	0	0	0	100
Control	0	0	0	0	0	50

1 Treatments are equivalent to pounds/acre on a surface area basis.

Table 47. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on mortality (%) of western larch (Larix occidentalis) grown in a vermiculite mix.

Treatment (lb/ac)[1]	5/05/86	5/20/86	6/23/86	8/20/86	10/03/86	4/29/87
Knapweed						
1,000	60	20	20	60	60	60
2,000	20	20	20	20	60	20
4,000	80	40	40	80	80	80
8,000	0	0	0	0	20	0
16,000	60	40	40	60	60	80
32,000	80	20	20	80	80	80
Elk Sedge						
1,000	40	20	20	40	40	60
2,000	0	0	0	0	0	0
4,000	40	20	20	40	40	40
8,000	60	60	60	60	60	60
16,000	20	0	0	20	20	20
32,000	40	40	40	40	40	80
Control	50	0	0	50	60	50

1 Treatments are equivalent to pounds/acre on a surface area basis.

Table 48. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on mortality (%) of Douglas-fir (Pseudotsuga menziesii) grown in a vermiculite mix.

Treatment (lb/ac)[1]	5/05/86	5/20/86	6/23/86	8/20/86	10/03/86	4/29/87
Knapweed						
1,000	80	80	80	80	80	80
2,000	80	80	80	80	80	80
4,000	40	40	60	60	60	60
8,000	40	40	60	60	60	60
16,000	40	40	60	60	60	80
32,000	60	60	60	60	60	80
Elk Sedge						
1,000	40	40	60	60	60	60
2,000	0	0	0	0	0	0
4,000	40	40	40	40	40	40
8,000	60	60	60	60	60	60
16,000	40	40	60	60	60	60
32,000	80	80	80	80	80	80
Control	20	20	20	20	20	20

[1] Treatments are equivalent to pounds/acre on a surface area basis.

Experiment 2: Influence of Spotted Knapweed Plant Material on Photosynthesis and Stomatal Conductance of Ponderosa Pine.

Methods

Possible inhibitory effects of spotted knapweed plant material on established tree seedlings were determined by measuring net photosynthesis, stomatal conductance, leaf injury, foliar growth and root growth of ponderosa pine potted in 3.75 liter pots. The growth medium for seedlings was either washed river sand or forest soil collected at Lubrecht Experimental Forest. The knapweed plant material was the same material as used for Experiment 1. Knapweed plant material was applied at the rates of 0, 2000, 8000, and 16,000 lb/ac to 3.7 liter pots on September 6, 1985. The knapweed plant material was either applied by mixing the plant material in the soil or sand medium or by applying all of the knapweed plant material to the surface of the soil. Each treatment, growth medium (sand or soil), and mix (surface or mixed into soil) was replicated four times in a randomized block design. Initial seedling size was blocked.

Ponderosa pine seedlings were grown in a Conviron PGW36 growth chamber set for 16-hr days. Temperature and humidity were varied throughout the day (Appendix 8). There was no set watering schedule. Soil was maintained in a moist condition by watering with approximately 250 ml on an every-other-day basis. Visual estimates of leaf injury were noted on a weekly basis. Physiological measurements of net photosynthesis and stomatal conductance were measured in April and May 1986. Because of the

length of time required to measure photosynthesis and stomatal conductance we measured seedlings growing in the forest soil on one day and seedlings growing in the sand culture on another day. Therefore, no direct comparison was made between soil and sand mediums.

All pine seedlings were sacrificed on October 30, 1986 after a series of water stress treatments. Leaf material, stems and roots were seperated and dried at 65° C.

Stomatal conductance (cm/s) and photosynthesis (mg $CO_2/m^2/s$) were measured with a LI-COR 6000. Physiological measurements were made in the growth chamber with the ambient temperature of 25° C and 425 QU. Calculations of stomatal conductance and photosynthesis were based on rate of change of humidity and CO_2 in a closed system. A calculation of intercellular CO_2 was also recorded (LI-COR, 1984). The LI-COR 6000 automatically logged and stored physiological and enviromental measurements and interfaced with an IBM personal computor for data "dumping". Photosynthetically active radiation, relative humidity, ambient CO_2, leaf temperature and air temperatures were also recorded using the LI-COR 6000 during stomatal conductance and photosynthesis measurements.

Results and Discussion

The addition of knapweed plant material had no observed visual effect on one-year-old ponderosa pine seedlings. Leaf necrosis, browning of needles or other signs of injury were not observed. There was also no difference in weight of leaves, roots, stems, total top weight or total weight between any

treatment; however, growth was greater in the sand medium as compared to the soil medium (Table 49). The addition of the knapweed by mixing into the soil or as a surface application did not affect any measured variable and therefore we have grouped the mixes for presentation of results.

Table 49. Effect of spotted knapweed treatments on leaf, stem, and root weights (g) of ponderosa pine (Pinus ponderosa) grown in a forest soil or sand culture.

Treatment[1] (lb/ac)	Forest Soil			Sand Culture		
	Leaf Wt.	Stem Wt.	Root Wt.	Leaf Wt.	Stem Wt.	Root Wt.
0	4.7	2.4	2.2	6.4	4.3	6.2
2,000	5.4	2.5	2.2	9.6	4.7	5.6
8,000	5.7	2.9	2.8	8.1	3.2	3.5
16,000	4.6	3.5	2.7	6.1	3.1	4.5

[1] Treatments are listed in their equivalents to lb/ac.

The only observable impact of the knapweed plant litter was a hydrophobic effect. At the 8000 and 16,000 lb/ac equivalent treatments the knapweed on the soil surface caused the water to pond as if the knapweed litter was hydrophobic. The ponding of water slowed water entry but probably did not affect total water supply to the potted seedlings. This hydrophobic effect of the litter was probably caused by the heavy addition of organic matter in a finely ground structure more than to a chemical compound in the material.

There was no significant treatment effect of knapweed

treatments on photosynthesis (Tables 50 and 51). There were differences in stomatal conductance (Tables 51 and 53) on April 3 for the forest-soil-grown plants and May 11 for the sand-grown plants. Date of measurement was a significant factor in photosynthesis and stomatal conductance which is believed to be associated with differences in soil moisture (watering schedule). There were no significant treatment by date interactions.

The increase in stomatal conductance for the 16,000 lb/ac treatment was not consistent across dates and may be more of an artifact than a significant physiological effect. If the knapweed plant material was causing an interuption in stomatal control there should have been more of a trend as knapweed litter increased and should have also been more apparent in growth and photosynthesis.

Table 50. Influence of knapweed treatments on photosynthesis (mg $CO_2/m^2/s$) of ponderosa pine (Pinus ponderosa) grown in a forest soil.

Treatment (lb/ac)[1]	Date				
	Apr 3	Apr 10	Apr 21	Apr 28	May 7
0	0.27	0.12	0.09	0.12	0.05
2,000	0.33	0.11	0.13	0.13	0.09
8,000	0.44	0.15	0.13	0.14	0.08
16,000	0.45	0.13	0.11	0.16	0.09

[1] Treatments are listed as their equivalent in lb/ac.

Table 51. Influence of knapweed treatments on stomatal conductance (cm/s) of ponderosa pine (*Pinus ponderosa*) grown in a forest soil.

Treatment (lb/ac)[1]	Date				
	Apr 3	Apr 10	Apr 21	Apr 28	May 7
0	0.25a[2]	0.13a	0.10a	0.11a	0.13a
2,000	0.26ab	0.11a	0.12a	0.12a	0.14a
8,000	0.31b	0.16ab	0.13a	0.14a	0.15a
16,000	0.23a	0.18b	0.11a	0.14a	0.16a

[1] Treatments are listed as their equivalent in lb/ac.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 52. Influence of knapweed treatments on photosynthesis (mg $CO_2/m^2/s$) of ponderosa pine (*Pinus ponderosa*) grown in a sand medium.

Treatment (lb/ac)[1]	Date				
	Apr 9	Apr 22	Apr 30	May 8	May 11
0	0.14	0.16	0.12	0.14	0.39
2,000	0.36	0.15	0.14	0.13	0.39
8,000	0.16	0.14	0.12	0.15	0.33
16,000	0.14	0.13	0.12	0.14	0.47

[1] Treatments are listed as their equivalent in lb/ac.

Table 53. Influence of knapweed treatments on stomatal conductance (cm/s) of ponderosa pine (Pinus ponderosa) grown in a sand medium.

Treatment (lb/ac)[1]	Date				
	Apr 9	Apr 22	Apr 30	May 8	May 11
0	0.12a[2]	0.12a	0.10a	0.14a	0.30a
2,000	0.13a	0.12a	0.12a	0.17a	0.38a
8,000	0.15a	0.10a	0.10a	0.12a	0.28a
16,000	0.13a	0.12a	0.10a	0.14a	0.57b

[1] Treatments are listed as their equivalent in lb/ac.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Experiment 3: Influence of Knapweed Leaves on Germination, Growth and Survival of Lodgepole Pine, Ponderosa Pine, Douglas-fir and Western Larch.

Methods

Potential inhibitory effects of spotted knapweed leaf material were tested on germination, survival and height growth of lodgepole pine, ponderosa pine, Douglas-fir and western larch planted in 216 cm^3 plastic growth containers at the School of Forestry greenhouse. Treatments consisted of five levels of knapweed plant material, five identical levels of elk sedge plant material and a control applied to a soil mix. Ponderosa pine and Douglas-fir were also grown in a sand medium. The five levels of spotted knapweed and elk sedge used as treatments were: (1) 0.72 g, (2) 1.80 g, (3) 3.60 g, (4) 5.40 g, and (5) 7.2 g. These rates were equivalent to 2,000 kg/ha, 5,000 kg/ha, 10,000 kg/ha,

15,000 kg/ha, and 20,000 kg/ha for the container surface area of 36 cm^2.

On April 20, 1987 the treatments were arranged in a randomized block design with four replications (4 containers) per treatment. For the first three levels of added plant material, the plant material was applied to the surface of the soil or sand and gently mixed into the surface of the growth medium. For the other treatments the plant material was mixed with about the top 50% of the growth medium in the container. For each tree species we planted 20 seeds into each container (replication) on April 21, 1987. Percent germination of ponderosa pine, Douglas-fir, western larch, and lodgepole pine was 68%, 72%, 53%, and 67%, respectively.

Possible inhibitory effects of added plant material was tested by counting the number of live tree seedlings (germination and survival) from April 30, 1987 to June 6, 1987 and by measuring average tree height of living tree seedling on three dates for ponderosa pine and two dates for the other species. Tree seedlings were counted on April 30, May 1, May 2, May 4, May 5, May 7, May 8, May 11, May 12, May 14, May 16 May 18, May 22, June 2, and June 8 and recorded as a percent (number counted/ number planted * 100). We have chosen to present the results for germination and survival for April 30, May 4, May 8, May 12, May 22, June 2 and June 8 (those dates at least 4 days apart) for brevity. All data were analyzed at the 0.05 level of probability using analysis of variance procedures. Data were transformed using an arcsine transformation when necessary to achieve

homogenity of variances. If analysis of variance was significant we used the new Duncan's multiple range test for mean separation (Steel and Torrie, 1980)

The knapweed plant material for this experiment consisted of current year's growth of knapweed leaves collected in August 1986. Immediately after collection the knapweed leaves were placed in a convection oven and dried for 5 days at 65° C. The knapweed material was mixed and ground with a Wiley mill and a 2 mm screen.

The elk sedge plant material consisted of elk sedge leaves collected during the summer of 1985. This plant material had also been dried in a convection oven after collection, ground with a Wiley mill to pass a 60 mesh screen, and stored in air tight containers.

Douglas-fir. For Douglas-fir in the sand culture germination and survival was decreased for all knapweed and elk sedge treatments except for the 2,000 kg/ha knapweed treatment (Table 54). Because there was no difference in germination and survival of equivalent knapweed and elk sedge treatments it is not possible to determine if there was an allelopathic effect. Apparently the addition of organic matter increased fungal or bacterial problems. Average heights of living Douglas-fir seedlings are presented in Table 55 but no statistical analysis was attempted because of the high number of missing values (no live trees) for most treatments.

There was no difference in germination and survival of Douglas-fir grown in the forest soil for any treatment (Table

Table 54. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on germination of Douglas-fir (Pseudotsuga menziesii) grown in a sand medium.

Treatment (kg/ha)[1]	May 4	May 8	May 12	May 16	May 22	June 2	June 8
Knapweed							
2,000	8a[2]	17ab	25ab	29b	25ab	17b	13b
5,000	4a	5bc	5c	8bc	8bc	8b	8b
10,000	0a	0c	0c	0c	0c	0b	0b
15,000	0a	0c	0c	0c	0c	0b	0b
20,000	0a	0c	0c	0c	0c	0b	0b
Elk Sedge							
2,000	0a	4bc	8bc	8bc	4bc	4b	4b
5,000	0a	0c	0c	0c	0c	0b	0b
10,000	0a	0c	0c	0c	0c	0b	0b
15,000	0a	0c	0c	0c	0c	0b	0b
20,000	0a	0c	0c	0c	0c	0b	0b
Control	6a	23a	42a	52a	44a	44a	34a

[1] Treatments are in kilogram/hectare equivalence.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 55. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on height of Douglas-fir (Pseudotsuga menziesii) grown in a sand medium and western larch and lodgepole pine grown in a soil mix.

Treatment (kg/ha)[1]	Douglas-fir		Western Larch		Lodgepole Pine	
	May 12	June 2	May 12	June 2	May 12	June 2
Knapweed						
2,000	1.9	1.4	2.1a	2.9b	3.0a	2.8a
5,000	1.0	1.1	1.6a	2.7b	2.2a	2.6a
10,000	-	-	1.8a	2.5b	2.8a	2.7a
15,000	-	-	1.8a	2.0a	1.8a	2.2a
20,000	-	-	2.0a	-	3.2a	2.8a
Elk Sedge						
2,000	1.1	0.7	1.7a	2.2b	2.2a	2.6a
5,000	-	0.8	1.7a	2.3b	2.5a	2.6a
10,000	-	-	1.9a	2.4b	2.9a	2.2a
15,000	-	-	1.6a	1.9b	2.2a	2.1a
20,000	-	-	1.3a	2.0b	1.6a	2.1a
Control	2.0	2.7	1.5a	2.5b	2.7a	2.5a

[1] Treatments are in kilogram/hectare equivalence.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

56). Douglas-fir suffered low survival because of damping off. It appeared that the addition of large amounts of organic matter as knapweed or elk sedge litter resulted in a trend of decreased rates of germination and survival.

Western Larch: Germination and survival of western larch was decreased for the 20,000 kg/ha knapweed treatment as compared to the check for all dates except May 4 (Table 57). The 10,000 and 15,000 kg/ha knapweed treatments also reduced germination and survival of western larch on May 16, May 22, June 2 and June 8 as compared to the check. By June 8 there were no surviving trees in the 10,000, 15,000 and 20,000 kg/ha knapweed treatments. A comparison of the knapweed and elk sedge treatments revealed reduced germination and survival of western larch for the 5,000 and 20,000 kg/ha treatments of knapweed but there was no difference between the 15,000 kg/ha treatments. There was also no difference in average height of living trees on either date measured (Table 55).

For western larch the knapweed treatments of 10,000, 15,000, and 20,000 kg/ha rates were having an inhibitory effect on germination and survival. It was apparent that added elk sedge could also cause inhibition of germination, possibly by increasing "damping off" problems. Therefore, it is difficult to seperate the inhibitory effects of a chemical(s) in the plant material or an effect of increased contamination or growth of fungi or bacteria in the growth medium by addition of plant material. However, because of the larger differences caused by knapweed and because of trends related to increases in added

Table 56. Influence of additions of knapweed (<u>Centaurea maculosa</u>) and elk sedge (<u>Carex geyeri</u>) plant material on germination of Douglas-fir (<u>Pseudotsuga menziesii</u>) grown in a vermiculite mix.

Treatment (kg/ha)[1]	May 12	May 16	May 22	June 2	June 8
Knapweed					
2,000	12	4	8	12	12
5,000	0	0	0	0	0
10,000	0	4	4	0	0
15,000	0	0	4	0	0
20,000	0	0	0	0	0
Elk Sedge					
2,000	8	17	17	17	13
5,000	0	0	0	0	0
10,000	0	0	0	0	0
15,000	0	4	4	4	4
20,000	0	0	0	0	0
Control	11	17	19	13	9

[1] Treatments are in kilogram/hectare equivalence.

Table 57. Influence of additions of knapweed (<u>Centaurea maculosa</u>) and elk sedge (<u>Carex geyeri</u>) plant material on germination of western larch (<u>Larix occidentalis</u>) grown in a vermiculite mix.

Treatment (kg/ha)[1]	May 4	May 8	May 12	May 16	May 22	June 2	June 8
Knapweed							
2,000	17a[2]	33a	40abc	47ab	47ab	47ab	45abc
5,000	8abc	22abcd	37abcd	28bc	27bcde	25bcd	20cde
10,000	3bc	10bcd	15bcde	12cd	5e	3d	0e
15,000	3bc	12abcd	13cde	12cd	7de	2d	0e
20,000	0c	0d	2e	2d	2e	0d	0e
Elk Sedge							
2,000	15ab	28abc	60a	62a	60a	60a	58a
5,000	18a	33a	43ab	50ab	53a	58a	52ab
10,000	5abc	25abc	38abcd	42ab	47ab	45ab	43abc
15,000	0c	7cd	10de	15cd	12cde	13cd	12de
20,000	7abc	15abcd	33abcd	32bc	35abcd	37abc	30bcd
Control	8abc	30ab	40abc	42ab	40abc	41ab	38abcd

[1] Treatments are in kilogram/hectare equivalence.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

knapweed material, it appears that knapweed was causing inhibiton of germination and survival on western larch.

Lodgepole Pine: Germination and survival was reduced for the 20,000 kg/ha knapweed for all dates except April 30 and May 4 when compared to the check, 2,000 kg/ha knapweed treatment or the 2,000, 5,000 and 10,000 kg/ha elk sedge treatments (Table 58). There was an apparent trend of decreased germination and survival of the 10,000, 15,000 and 20,000 kg/ha knapweed treatments as compared to the check or equivalent rates of elk sedge. Height growth of seedlings was not different between any treatments (Table 55).

Ponderosa Pine: For ponderosa pine growing in the forest soil germination and survival was decreased for the 20,000 kg/ha knapweed treatment compared to the check on April 30, June 2 and June 8 (Table 59). However, the 20,000 kg/ha knapweed treatment was not different from the 20,000 elk sedge treatment for any date. There appeared to be a trend of decreased germination and survival as knapweed or elk sedge litter increased. Although the means were not different between the knapweed and elk sedge treatment, the average mean difference between equivalent amounts of added knapweed material and elk sedge material was about 7% lower for the knapweed treatments. Average height of living trees was reduced for the 20,000 kg/ha knapweed treatment compared to the check and all elk sedge treatments except 2,000 kg/ha (Table 60).

When ponderosa pine was grown in a sand medium the effect of the added knapweed was much more significant (Table 61).

Table 58. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on germination of lodgepole pine (Pinus contorta) grown in a vermiculite mix.

Treatment (kg/ha)[1]	Apr 30	May 4	May 8	May 12	May 16	May 22	June 2	June 8
Knapweed								
2,000	27ab[2]	45a	52ab	48ab	53ab	53ab	53a	45a
5,000	3bc	20a	23bc	23bc	23bc	22bcd	18bc	17bc
10,000	10abc	17a	22bc	22bc	20bc	22bcd	17bc	12bc
15,000	3bc	13a	17bc	17bc	17bc	15cd	15bc	5c
20,000	8bc	13a	8c	7c	8c	8d	3c	3c
Elk Sedge								
2,000	33a	60a	60a	63a	63a	63a	63a	52a
5,000	32a	47a	55a	57a	57a	57a	55a	50a
10,000	12abc	43a	45ab	43ab	45ab	47ab	43ab	38ab
15,000	13abc	30a	32abc	33ab	35ab	35abcd	33ab	35ab
20,000	2c	28a	33abc	38ab	38ab	38abc	36ab	35ab
Control	14abc	43a	46ab	41ab	42ab	42abc	41ab	31ab

[1] Treatments are in kilogram/hectare equivalence.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 59. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on germination of ponderosa pine (Pinus ponderosa) grown in a vermiculite mix.

Treatment (kg/ha)[1]	Apr 30	May 4	May 8	May 12	May 16	May 22	June 2	June 8
Knapweed								
2,000	29ab[2]	35a	37a	35a	37a	37ab	37ab	37ab
5,000	25ab	46a	48a	42a	46a	45a	46a	46ab
10,000	12ab	27a	29a	27a	25a	25ab	21ab	20abc
15,000	15ab	27a	27a	19a	19a	19ab	19ab	17bc
20,000	6b	15a	15a	15a	15a	10a	10b	10c
Elk Sedge								
2,000	29ab	40a	40a	35a	40a	37ab	38ab	38ab
5,000	25ab	50a	50a	46a	48a	48a	48a	48a
10,000	29ab	31a	35a	35a	35a	35ab	31ab	31ab
15,000	25ab	38a	40a	31a	38a	38ab	38ab	38ab
20,000	4b	19a	19a	19a	19a	19ab	19ab	19abc
Control	37a	44a	43a	45a	45a	46a	44ab	44ab

[1] Treatments are in kilogram/hectare equivalence.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 60. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on height of ponderosa pine grown in a sand medium.

Treatment (kg/ha)[1]	Soil Medium			Sand Medium		
	May 7	May 12	June 2	May 7	May 12	June 2
Knapweed						
2,000	4.3abc[2]	5.6a	5.5a	6.0cd	6.8d	6.5c
5,000	4.7bc	5.5a	6.5a	4.6c	4.6c	5.7c
10,000	4.1ab	4.6a	6.2a	6.9d	6.9d	6.8c
15,000	3.8ab	5.9a	6.1a	2.1b	2.1b	3.5b
20,000	3.0a	3.7a	4.2a	-	-	-
Elk Sedge						
2,000	4.4abc	5.9a	6.6a	5.6cd	6.0cd	6.3c
5,000	5.0bc	6.5a	6.0a	6.3cd	6.6d	6.1c
10,000	5.8c	5.1a	6.2a	5.4cd	5.7cd	6.2c
15,000	5.0bc	5.6a	5.9a	5.5cd	5.8cd	6.4c
20,000	5.2bc	5.8a	5.3a	5.0cd	5.2cd	6.0c
Control	5.8c	5.8a	6.1a	6.3cd	6.5d	7.2c

[1] Treatments are in kilogram/hectare equivalence.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Table 61. Influence of additions of knapweed (Centaurea maculosa) and elk sedge (Carex geyeri) plant material on germination of ponderosa pine (Pinus ponderosa) grown in a sand medium.

Treatment (kg/ha)[1]	Apr 30	May 4	May 8	May 12	May 16	May 22	June 2	June 8
Knapweed								
2,000	35a[2]	40a	37a	33ab	37ab	37ab	33a	31ab
5,000	6c	17bcd	25ab	21bcd	17bcd	17bcd	17bc	17bcd
10,000	4c	4cd	4bc	4d	4d	4d	4c	4d
15,000	0c	2d	2c	4d	4d	4d	4c	2d
20,000	0c	0d	0c	0d	0d	0d	0c	0d
Elk Sedge								
2,000	31a	35ab	35a	35ab	37ab	37ab	37a	37ab
5,000	29ab	39ab	40a	40ab	42ab	42ab	38a	38ab
10,000	12bc	25abc	25ab	25ab	25abc	25abc	27ab	27abc
15,000	8c	27ab	35a	31ab	31ab	31ab	27ab	27abc
20,000	4c	25abc	25ab	27ab	27abc	27ab	27ab	27abc
Control	39a	46a	47a	47a	48a	47a	47a	45a

[1] Treatments are in kilogram/hectare equivalence.
[2] Means followed by a similar letter in the same column are not different at the 0.05 level of probability.

Knapweed added at the rates of 10,000, 15,000, and 20,000 kg/ha reduced ponderosa pine survival and germination on all dates when compared to the check. Knapweed added at the rate of 5,000 kg/ha also reduced ponderosa pine germination and survival on all dates except May 8. Ponderosa pine germination and survival were decreased only on April 30 for any of the elk sedge treatments. In general, the 10,000, 15,000 and 20,000 kg/ha knapweed treatments had lower germination and survival of ponderosa pine as compared to the elk sedge treatments. For seedlings that germinated and survived there was a difference in height growth for only the 15,000 kg/ha knapweed treatment as compared to the other treatments (Table 60).

Experiment 4: Influence of Control of Spotted Knapweed on Growth and Survival of Planted Ponderosa Pine and Douglas-fir.

Methods

The effect of spotted knapweed control on survival and growth of ponderosa pine and Douglas-fir seedlings was determined by spraying the herbicide, Clopyralid, on paired plots on a clearcut that had heavy knapweed coverage. Clopyralid, at 0.25 lb. a.i./acre, is effective in controlling knapweed but has no known deleterious effect on conifer seedlings. Initially we attempted to model the effect of knapweed on tree seedling survival by examining the relationship between coverage of knapweed and tree seedling numbers. It was difficult to determine how long the knapweed had been established on sites and to determine if tree seedlings had been planted. Other compounding factors appeared to be livestock and big game damage to tree seedlings and other competing vegetation. For example, for the dryer sites where knapweed was a problem, tree seedling numbers were very low or not present as a young seedling (less then five-years old). Therefore, we controlled tree numbers and applied a treatment to determine if an effect of knapweed existed.

Ponderosa pine and Douglas-fir seedlings were planted on April 1, 1986 on a dry clearcut located in Section 16 on the Lubrecht Experimental Forest. The clearcut is a Douglas-fir/ snowberry habitat type at an elevation of 1,230 m with a 10%

slope to the south. The area had been clearcut in 1965 and regeneration has been very poor. Herbaceous species dominated the clearcut with spotted knapweed being a large component of the plant community.

Treatments were knapweed control with clopyralid (0.25 lb/a.i./acre) and no knapweed control (check). Treatment plots were 1 m^2 circular plots. The plots were surface-scarified using a garden hoe to remove competing vegetation. Treatments were paired (12 paired plots) with two ponderosa pine and two Douglas-fir seedlings planted on each site. Tree seedlings were containerized stock provided by the Department of State Lands. Plots chosen to receive the herbicide treatment or no treatment were determined by a coin flip and knapweed was sprayed on May 26, 1986. Seedlings were planted on April 1, 1986 while there was snow on the clearcut. The site was protected from livestock.

Survival data was analyzed using a Chi-square anlysis. Heights of tree seedlings and plant coverage were analyzed using a paired T-test.

<u>Results and Discussion</u>

Control of spotted knapweed increased survival of planted ponderosa pine but not that of Douglas-fir (Table 62). Survival of Douglas-fir was poor and averaged only 15% by two growing seasons post-treatment. Control of knapweed resulted in 92% survival of ponderosa pine one growing season post-treatment compared to 62% for the check. Survival of ponderosa pine remained greater for the clopyralid treatment two growing seasons post-treatment compared to the check. However, the percent

difference between the clopyralid and check had decreased to 21% after two growing seasons compared to 30% after the first growing season.

We found no difference in the mean heights of seedlings for the no knapweed area compared to seedling growing with knapweed. Heights of ponderosa pine seedlings in July and October 1987 were 20.2 cm and 21.6 cm, respectively, for the check compared to 22.5 cm and 22.8 cm for the clopyralid treatment. Douglas-fir seedling heights were 15.0 cm and 15.0 cm, respectively, for the check in July and October 1987 compared to 13.1 cm and 14.8 cm, respectively, for the clopyralid treatment.

An obvious impact of Clopyralid was a change in plant composition and amount of bare ground (Table 63). The grass species which increased following knapweed control were Kentucky bluegrass and timothy. Native graminoids had a trend of increased coverage but apparently reponded more slowly to the increase in resources. The only forb that was frequent enough to have a significant increase in coverage was wooly mullen. However, we believe that rose pussytoes, virginia strawberry, *Penstemon* sp. and butter and eggs (*Linaria vulgaris*) had a trend in increased coverage. The dominant shrub was snowberry which showed a trend of decreased coverage on the sprayed plots.

The increase in grass coverage for the clopyralid treatment would certainly have a positive benefit for livestock production on this site but the grasses would also compete with tree growth. It is likely that the reason for finding no difference in tree heights after two growing seasons was because competition for

water was equal for both treatments. Knapweed appears to compete very effectively for water and grasses and other native plants were of low vigor. The advantage of the control of knapweed was to give the planted tree seedlings a period of time when competition for water was not severe because of the low vigor of grasses and the removal of the knapweed.

Table 62. Influence of knapweed control with clopyralid on tree seedling survival.

Treatment	Survival (%) by Date					
	10/03/86		7/15/87		10/01/87	
	Pine	Fir	Pine	Fir	Pine	Fir
Clopyralid	92*	40	83*	20	79*	15
Check	62	30	58	15	58	15

* Signifies that means within the same column are different at the 0.10 level of probability.

Table 63. Influence of clopyralid two growing seasons post-treatment on coverage (percent) of knapweed, other forbs, introduced grasses, native grasses, shrubs and bareground.

Vegetation Categories (%) and Bareground (%)	Treatment	
	Check	Clopyralid
Knapweed	60 a[1]	3 b
Forbs	1 b	8 a
Introduced Grasses	1 b	16 a
Native Graminoids	2 a	7 a
Shrubs	6 a	3 a
Bareground	30 b	64 a

[1] Means followed by a similar letter in the same row are not significant at the 0.05 level of probability.

Summary

Our treatments using the top-growth of knapweed plants did not cause a phytotoxic effect to germination or growth of lodgepole pine, Douglas-fir or western larch, or to photosynthesis or growth of ponderosa pine seedlings. However, phytotoxicity to germination and survival was observed when only leaf material of knapweed was applied as treatments. Phytotoxicity effects were observed for western larch, lodgepole pine and ponderosa pine. These results would support the findings of Locken and Kelsey (1987) that the phytotoxic agent is in the leaves of spotted knapweed. It was also evident that the addition of any type of organic matter increased mortality, probably by increasing energy source to soil microorganisms.

Phytotoxic effects of knapweed leaves to germination and survival were more evident for ponderosa pine when the growth medium was sand than when the growth medium was a vermiculite mix. The more evident phytotoxicity caused by knapweed leaves applied to the sand medium was related to two factors: (1) Within treatment variation was much greater in seedlings grown in vermiculite soil mix because of "damping off" and (2) Toxicity was probably decreased in the vermiculite mix because of absorption of the toxic compound to soil particles and greater degradation of cnicin. Locken and Kelsey (1987) stated that the structure of cnicin was such that it would be easily degraded by microorganisms. They also found very little cnicin in the soil in areas dominated by knapweed which suggests breakdown of the

compound.

Locken and Kelsey (1987) isolated cnicin from the leaves of spotted knapweed and showed that the substance is phytotoxic to several plant species when applied to germinating seeds in a petri dish. They also found little cnicin in the soil which suggests that the substance is easily degraded. Locken and Kelsey (1987) concluded that cnicin would not be strongly allelopathic in a natural system; however, they did not completely discount the probability of another allelopathic chemical. In our field study ponderosa pine survival was increased where knapweed was controlled. This increase in survival was probably related to a decrease in competition for water and was not believed to be related to allelopathy since knapweed had been growing on the site and was still present in the soil.

The large amount of knapweed leaves necessary to cause a significant decrease in germination and survival of ponderosa pine, western larch, and lodgepole pine suggests that there are other factors leading to the success of knapweed on clearcuts and grassland sites. From our research and other studies we believe that knapweed's success is related to its ability to compete for resources. Once knapweed is controlled there is a rapid increase in growth of existing plants because of additional resources. The increase in growth is about equal to the amount of knapweed controlled. Locken and Kelsey (1987) believed that the large concentration of cnicin in the leaves of knapweed decreased knapweed palatability and thus acted as an anti-herbivory,

possibly from mammals, insects and disease agents. A lack of grazing on knapweed by mammals, insects, and/or soil fauna would greatly increase its competitive ability on many sites. For example, bluebunch wheatgrass may require six years of non-use for recovery from a one-time removal of 50% of the shoot system (Mueggler 1975). If competing vegetation was reduced, then bluebunch wheatgrass vigor was good, but when vegetation was allowed to compete with bluebunch wheatgrass the vigor of bluebunch wheatgrass was greatly reduced (Mueggler 1975).

Knapweed begins growth very early in the spring which increases its ability to compete for resources. When knapweed was introduced into North America natural enemies such as herbivores and diseases were left behind in Europe. It is very likely that the ability of knapweed to compete for water and nutrients is greatly increased because of less utilization by insects, mammals and possibly from soil fauna when compared to the surrounding vegetation. Therefore, it is our belief that the introduction of knapweed has changed the competitive balance of many sites in western Montana. This competitive imbalance has shifted these sites to knapweed dominated sites.

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APPENDICES

APPENDIX 1. Plant Species Found on Each Site

CLEARWATER SITE

Scientific name	Common name
Grasses	
Bromus tectorum	cheatgrass
Danthonia unispicata	onespike oatgrass
Elymus spicatus	bluebunch wheatgrass
Festuca idahoensis	Idaho fescue
Festuca scabrella	rough fescue
Koeleria macrantha	prairie junegrass
Poa pratensis	Kentucky bluegrass
Poa secunda	sandberg bluegrass
Stipa occidentalis	western needlegrass
Grass-like	
Carex filifolia	threadleaf sedge
Forbs	
Achillea millefolium	western yarrow
Agoseris glauca	pale agoseris
Antennaria microphylla	rose pussytoes
Antennaria parvifolia	small-leaf pussytoes
Arabis glabra	tower rockcress
Arabis holboellii	Holboell rockcress
Arabis nuttallii	Nuttall rockcress
Arenaria capillaris	fescue sandwort
Arenaria serpyllifolia	thymeleaved sandwort
Arnica fulgens	arnica fulgens
Balsamorhiza sagitatta	arrowleaf balsamroot
Camelina microcarpa	littlepod falseflax
Castilleja lutescens	stiff yellow Indian paintbrush
Centaurea maculosa	spotted knapweed
Claytonia lanceolata	western springbeauty
Collinsia parviflora	small-flowered blue-eyed mary
Collomia linearis	narrow leaved collomia
Delphinium bicolor	low larkspur
Descurainia richardsonii	Richardson tansymustard
Dianthus armeria	deptford pink
Dodecatheon spp.	shooting star
Draba nemorosa	woods draba
Epilobium paniculatum	panicled willow-herb
Erigeron compositus	fernleaf fleabane
Erigeron pumilus	fleabane
Eriogonum umbellatum	sulfer eriogonum
Filago arvensis	field fluffweed

APPENDIX 1 (cont.)

Fritillaria pudica	yellow bell
Geranium spp.	geranium
Geum triflorum	prairiesmoke
Grindelia nana	low gumweed
Hackelia deflexa	nodding stickseed
Hesperis matronalis	sweet rocket
Heterotheca villosa	golden-aster
Hieracium cynoglossoides	houndtongue hawkweed
Hypericum perforatum	common St. John's-wort
Lepidium virginicum	Virginia pepperweed
Lewisia rediviva	bitterroot
Lithophragma parviflorum	smallflower woodlandstar
Lithospermum ruderale	western gromwell
Lomatium macrocarpum	large-fruited lomatium
Lomatium triternatum	nineleaf lomatium
Lupinus sericeus	silky lupine
Lycopodium spp.	club moss
Mertensia spp.	bluebells
Microsteris gracilis	microsteris gracilis
Myosotis micrantha	slender forget-me-not
Phacelia linearis	linear-leaf phacelia
Polygonum douglasii	Douglas knotweed
Potentilla glandulosa	gland cinquefoil
Potentilla gracilis	northwest cinquefoil
Rumex acetosella	sheep sorrel
Saxifraga occidentalis	western saxifrage
Sedum stenopetalum	stonecrop
Senecio integerrimus	lambstongue groundsel
Silene antirrhina	sleepy silene
Silene scouleri	catchfly
Sisymbrium altissimum	tumblemustard
Taraxacum officinale	common dandelion
Tragopogon dubius	common salsify
Verbascum thapsus	wooley mullein
Zigadenus venenosus	death camas

Shrubs

Artemisia cana	silver sagebrush

APPENDIX 1 (cont.)

LOLO SITE

Scientific name	Common name
Grasses	
Agrostis interrupta	agrostis interrupta
Bromus japonicus	Japanese brome
Bromus mollis	soft chess
Bromus tectorum	cheatgrass
Danthonia unispicata	onespike oatgrass
Elymus spicatus	bluebunch wheatgrass
Festuca scabrella	rough fescue
Koeleria macrantha	prairie junegrass
Phleum pratense	timothy
Poa longiligula	longtongue mutton grass
Poa secunda	sandberg bluegrass
Stipa occidentalis	western needlegrass
Grass-like	
Carex filifolia	threadleaf sedge
Forbs	
Achillea millefolium	western yarrow
Agastache urticifolia	nettle-leaf giant hyssop
Agoseris glauca	pale agoseris
Alyssum alyssoides	pale alyssum
Androsace septentrionalis	northern androsace
Antennaria microphylla	rose pussytoes
Antennaria parvifolia	small-leaf pussytoes
Arabis holboellii	Holboell rockcress
Arabis nuttallii	Nuttall rockcress
Arenaria capillaris	fescue sandwort
Arenaria serpyllifolia	thymeleaved sandwort
Arnica fulgens	arnica fulgens
Aster stenomeres	northwest aster
Astragalus miser	weedy milk-vetch
Balsamorhiza sagittata	arrowleaf balsamroot
Camelina microcarpa	littlepod falseflax
Capsella bursa-pastoris	shepherd's purse
Carduus nutans	musk thistle
Castilleja lutescens	stiff yellow Indian paintbrush
Centaurea maculosa	spotted knapweed
Clarkia pulchella	clarkia
Claytonia lanceolata	western springbeauty
Collinsia parviflora	small-flowered blue-eyed mary
Collomia linearis	narrow leaved collomia
Comandra umbellata	pale bastard toadflax

APPENDIX 1 (cont.)

Convolvulus arvensis	field bindweed
Cuscuta epithymum	clover dodder
Dianthus armeria	deptford pink
Dodecatheon spp.	shooting star
Draba nemorosa	woods draba
Draba verna	spring draba
Epilobium paniculatum	panicled willow-herb
Erigeron pumilus	fleabane
Erigeron speciosus	Oregon fleabane
Erigeron subtrinervis	three-veined fleabane
Eriogonum umbellatum	sulfer eriogonum
Fritillaria pudica	yellow bell
Gaillardia aristata	blanketflower
Geum triflorum	prairiesmoke
Grindelia nana	low gumweed
Heterotheca villosa	golden-aster
Hieracium cynoglossoides	houndtongue hawkweed
Lewisia rediviva	bitteroot
Lithophragma parviflorum	smallflower woodlandstar
Lithospermum ruderale	western gromwell
Lomatium macrocarpum	large-fruited lomatium
Lomatium triternatum	nineleaf lomatium
Lupinus sericeus	silky lupine
Mertensia oblongifolia	bluebells
Microsteris gracilis	microsteris gracilis
Montia linearis	Indian lettuce
Myosotis micrantha	slender forget-me-not
Orthocarpus tenuifolius	owl clover
Polygonum douglasii	Douglas knotweed
Potentilla gracilis	northwest cinquefoil
Rumex acetosella	sheep sorrel
Saxifraga occidentalis	western saxifrage
Senecio spp.	groundsel
Silene spp.	silene
Solidago missouriensis	goldenrod
Taraxacum officinale	common dandelion
Tragopogon dubius	common salsify
Triteleia grandiflora	wild hyacinth
Verbascum thapsus	wooley mullein
Veronica arvensis	common speedwell
Viola nuttallii	yellow violet
Zigadenus venenosus	death camas

Shrubs

Artemisia cana	silver sagebrush
Chrysothamnus viscidiflorus	green rabbitbrush
Rosa spp.	rose
Symphoricarpos occidenatalis	western snowberry

APPENDIX 1 (cont.)

THREEMILE SITE

Scientific name	Common name
Grasses	
Agrostis interrupta	agrostis interrupta
Bromus tectorum	cheatgrass
Elymus smithii	western wheatgrass
Festuca idahoensis	Idaho fescue
Koeleria macrantha	prairie junegrass
Phleum pratense	timothy
Poa bulbosa	bulbous bluegrass
Poa compressa	Canada bluegrass
Poa longiligula	longtongue mutton grass
Poa pratensis	Kentucky bluegrass
Forbs	
Achillea millefolium	western yarrow
Alyssum alyssoides	pale alyssum
Androsace septentrionalis	northern androsace
Antennaria microphylla	rose pussytoes
Antennaria parvifolia	small-leaf pussytoes
Arabis holboellii	Holboell rockcress
Arenaria serpyllifolia	thymeleaved sandwort
Arnica fulgens	arnica fulgens
Centaurea maculosa	spotted knapweed
Collinsia parviflora	small-flowered blue-eyed mary
Collomia linearis	narrow leaved collomia
Descurainia richardsonii	Richardson tansymustard
Draba nemorosa	woods draba
Draba verna	spring draba
Epilobium paniculatum	panicled willow-herb
Erigeron compositus	fernleaf fleabane
Erigeron speciosus	Oregon fleabane
Erodium cicutarium	three-veined fleabane
Filago arvensis	field fluffweed
Geranium spp.	geranium
Hackelia deflexa	nodding stickseed
Hesperis matronalis	sweet rocket
Hieracium cynoglossoides	houndtongue hawkweed
Hypericum perforatum	common St. John's-wort
Lepidium virginicum	Virginia pepperweed
Linaria vulgaris	butter and eggs
Lithophragma parviflorum	smallflower woodlandstar
Lupinus leucophyllus	velvet lupine
Lupinus sericeus	silky lupine
Medicago sativa	alfalfa
Microsteris gracilis	microsteris gracilis

APPENDIX 1 (cont.)

Montia linearis	Indian lettuce
Myosotis micrantha	slender forget-me-not
Penstemon spp.	penstemon
Plantago patagonica	plantain
Polygonum douglasii	Douglas knotweed
Potentilla glandulosa	gland cinquefoil
Potentilla gracilis	northwest cinquefoil
Rumex acetosella	sheep sorrel
Silene spp.	silene
Sisymbrium altissimum	tumblemustard
Thlaspi arvense	fanweed
Tragopogon dubius	common salsify
Verbascum thapsus	wooley mullein
Veronica arvensis	common speedwell

APPENDIX 2. Plot Diagram by Site

Lolo Site

Block 1	Block 2	Block 3
0.07 kg/ha Met methyl[1]	Control	0.28 kg/ha Clopyralid
0.28 kg/ha Pic + Clop[2]	0.14 kg/ha Picloram	0.14 kg/ha Clopyralid
0.42 kg/ha Pic + Clop	0.035 kg/ha Met methyl[3]	0.42 kg/ha Picloram
0.035 kg/ha Met methyl[3]	0.14 kg/ha Clopyralid[3]	0.28 kg/ha Picloram
0.14 kg/ha Clopyralid[3]	0.14 kg/ha Pic + Clop[3]	0.07 kg/ha Met methyl
0.14 kg/ha Pic + Clop[3]	0.42 kg/ha Clopyralid	0.42 kg/ha Pic + Clop
0.14 kg/ha Pic + Clop	0.28 kg/ha Picloram	0.14 kg/ha Clopyralid[3]
0.28 kg/ha Picloram	0.28 kg/ha Pic + Clop	0.035 kg/ha Met methyl[3]
0.42 kg/ha Clopyralid	0.14 kg/ha Pic + Clop	0.14 kg/ha Pic + Clop[3]
0.14 kg/ha Picloram	0.42 kg/ha Picloram	Control
0.14 kg/ha Clopyralid	0.035 kg/ha Met methyl	0.14 kg/ha Pic + Clop
0.42 kg/ha Picloram	0.28 kg/ha Clopyralid	0.14 kg/ha Met methyl
0.14 kg/ha Met methyl	0.42 kg/ha Pic + Clop	0.42 kg/ha Clopyralid
0.28 kg/ha Clopyralid	0.14 kg/ha Clopyralid	0.14 kg/ha Picloram
0.035 kg/ha Met methyl	0.07 kg/ha Met methyl	0.035 kg/ha Met methyl
Control	0.14 kg/ha Met methyl	0.28 kg/ha Pic + Clop

[1] Metsulfuron methyl [2] Picloram + Clopyralid [3] Burned plots

APPENDIX 2 (cont.)

<u>Clearwater Site</u>

Block 1	Block 2	Block 3
0.14 kg/ha Met methyl[1]	0.14 kg/ha Picloram	0.42 kg/ha Pic + Clop[2]
0.28 kg/ha Picloram	0.28 kg/ha Picloram	0.42 kg/ha Picloram
0.14 kg/ha Pic + Clop	0.14 kg/ha Clopyralid[3]	0.14 kg/ha Pic + Clop[3]
0.14 kg/ha Clopyralid[3]	0.035 kg/ha Met methyl[3]	0.035 kg/ha Met methyl[3]
0.035 kg/ha Met methyl[3]	0.14 kg/ha Pic + Clop[3]	0.14 kg/ha Clopyralid[3]
0.14 kg/ha Pic + Clop[3]	0.28 kg/ha Pic + Clop	0.14 kg/ha Pic + Clop
0.42 kg/ha Clopyralid	0.14 kg/ha Pic + Clop	0.14 kg/ha Clopyralid
0.28 kg/ha Clopyralid	0.14 kg/ha Clopyralid	0.28 kg/ha Clopyralid
Control	Control	0.28 kg/ha Pic + Clop
0.42 kg/ha Picloram	0.14 kg/ha Met methyl	0.14 kg/ha Picloram
0.28 kg/ha Pic + Clop	0.42 kg/ha Picloram	0.42 kg/ha Clopyralid
0.14 kg/ha Clopyralid	0.42 kg/ha Pic + Clop	0.07 kg/ha Met methyl
0.14 kg/ha Picloram	0.28 kg/ha Clopyralid	Control
0.07 kg/ha Met methyl	0.07 kg/ha Met methyl	0.035 kg/ha Met methyl
0.42 kg/ha Pic + Clop	0.42 kg/ha Clopyralid	0.28 kg/ha Picloram
0.035 kg/ha Met methyl	0.035 kg/ha Met methyl	0.14 kg/ha Met methyl

[1]Metsulfuron methyl [2]Picloram + Clopyralid [3]burned plots

APPENDIX 2 (cont.)

Threemile Site

Block 1	Block 2	Block 3
0.42 kg/ha Picloram	0.035 kg/ha Met methyl[1]	0.28 kg/ha Clopyralid
0.28 kg/ha Picloram	0.42 kg/ha Clopyralid	0.14 kg/ha Picloram
0.14 kg/ha Pic + Clop[2]	0.14 kg/ha Pic + Clop	0.42 kg/ha Clopyralid
0.14 kg/ha Clopyralid	0.28 kg/ha Pic + Clop	0.28 kg/ha Pic + Clop
0.07 kg/ha Met methyl	0.035 kg/ha Met methyl[3]	0.07 kg/ha Met methyl
0.035 kg/ha Met methyl	0.14 kg/ha Clopyralid[3]	0.28 kg/ha Picloram
0.28 kg/ha Pic + Clop	0.14 kg/ha Pic + Clop[3]	0.14 kg/ha Clopyralid
0.14 kg/ha Clopyralid[3]	0.42 kg/ha Picloram	0.035 kg/ha Met methyl
0.14 kg/ha Pic + Clop[3]	0.42 kg/ha Pic + Clop	0.14 kg/ha Pic + Clop[3]
0.035 kg/ha Met methyl[3]	0.07 kg/ha Met methyl	0.14 kg/ha Clopyralid[3]
0.14 kg/ha Met methyl	Control	0.035 kg/ha Met methyl[3]
0.42 kg/ha Pic + Clop	0.28 kg/ha Clopyralid	Control
0.42 kg/ha Clopyralid	0.14 kg/ha Picloram	0.42 kg/ha Picloram
Control	0.14 kg/ha Met methyl	0.14 kg/ha Met methyl
0.14 kg/ha Picloram	0.28 kg/ha Picloram	0.14 kg/ha Pic + Clop
0.28 kg/ha Clopyralid	0.14 kg/ha Clopyralid	0.42 kg/ha Pic + Clop

[1] Metsulfuron methyl [2] Picloram + Clopyralid [3] Burned plots

APPENDIX 3

Data means used for multiple comparison procedures

Table 1. Spotted knapweed standing crop (kg/ha)

Herbicide	Rate (kg/ha)	1985 Lolo	1986 Lolo	1986 Clearwater	1986 Threemile
Metsulfuron methyl[1]	0.035	455.6	1398.3	1254.4	1160.3
Metsulfuron methyl	0.035	586.6	775.8	1374.5	1362.1
Metsulfuron methyl	0.07	497.0	1485.3	1387.9	1594.7
Metsulfuron methyl	0.14	283.7	959.3	1076.4	1747.9
Clopyralid[1]	0.14	41.6	185.1	127.3	947.5
Clopyralid	0.14	45.0	167.8	289.2	252.7
Clopyralid	0.28	25.3	37.7	120.1	141.6
Clopyralid	0.42	21.6	55.2	68.6	120.7
Picloram & Clopyralid[1]	0.14	37.4	108.6	19.0	135.4
Picloram & Clopyralid	0.14	20.1	71.7	67.5	96.2
Picloram & Clopyralid	0.28	24.6	0.0	76.8	69.5
Picloram & Clopyralid	0.42	28.8	0.0	72.5	2.0
Picloram	0.14	79.2	4.6	283.5	211.7
Picloram	0.28	23.2	18.2	18.6	8.0
Picloram	0.42	25.4	0.0	0.6	0.1
Control		928.0	912.7	893.5	1234.6

[1] Burned plots

APPENDIX 3 (cont.)

Table 2. Spotted knapweed density (plants/m²)

Herbicide	Rate (kg/ha)	Lolo	Clearwater	Threemile
Metsulfuron methyl[1]	0.035	548.0	137.3	160.0
Metsulfuron methyl	0.035	466.6	354.6	298.7
Metsulfuron methyl	0.07	235.3	154.6	161.3
Metsulfuron methyl	0.14	185.3	199.3	168.7
Clopyralid[1]	0.14	81.3	54.7	80.0
Clopyralid	0.14	168.6	186.3	110.7
Clopyralid	0.28	49.3	169.3	33.0
Clopyralid	0.42	57.3	66.7	53.7
Picloram & Clopyralid[1]	0.14	41.3	23.0	38.0
Picloram & Clopyralid	0.14	29.3	44.0	21.3
Picloram & Clopyralid	0.28	0.0	36.0	18.7
Picloram & Clopyralid	0.42	0.0	17.3	3.3
Picloram	0.14	1.3	150.6	14.7
Picloram	0.28	0.0	14.0	2.0
Picloram	0.42	0.0	0.0	0.0
Control		764.8	344.0	238.67

[1] Burned plots

APPENDIX 3 (cont.)

Table 3. Standing crop (kg/ha) of prairie junegrass and kentucky bluegrass

Herbicide	Rate (kg/ha)	Prairie Junegrass[2]	Prairie Junegrass[3]	Kentucky Bluegrass[4]
Metsulfuron methyl[1]	0.035	92.3	58.9	202.3
Metsulfuron methyl	0.035	88.9	81.6	448.5
Metsulfuron methyl	0.07	63.7	74.0	365.6
Metsulfuron methyl	0.14	64.7	67.9	627.3
Clopyralid[1]	0.14	163.3	203.8	872.5
Clopyralid	0.14	216.9	179.9	1068.5
Clopyralid	0.28	330.0	212.6	1179.7
Clopyralid	0.42	352.7	159.9	1107.6
Picloram & Clopyralid[1]	0.14	296.3	194.9	940.2
Picloram & Clopyralid	0.14	193.4	186.2	1394.9
Picloram & Clopyralid	0.28	576.9	272.5	1196.1
Picloram & Clopyralid	0.42	396.3	163.1	1511.2
Picloram	0.14	264.0	307.4	1357.3
Picloram	0.28	297.3	256.2	1150.8
Picloram	0.42	659.5	173.8	1786.9
Control		41.7	38.8	519.4

[1] Burned plots
[2] Lolo site
[3] Clearwater site
[4] Threemile site

APPENDIX 3 (cont.)

Table 4. Total grass standing crop (kg/ha)

Herbicide	Rate (kg/ha)	Lolo	Clearwater	Threemile
Metsulfuron methyl[1]	0.035	595.9	551.9	338.7
Metsulfuron methyl	0.035	1042.9	572.1	546.8
Metsulfuron methyl	0.07	592.9	475.2	593.2
Metsulfuron methyl	0.14	770.4	696.9	747.3
Clopyralid[1]	0.14	1503.6	1024.5	949.6
Clopyralid	0.14	1351.7	1055.3	1434.5
Clopyralid	0.28	1636.6	1269.4	1390.6
Clopyralid	0.42	1773.6	1322.1	1433.2
Picloram & Clopyralid[1]	0.14	1582.9	995.2	1050.8
Picloram & Clopyralid	0.14	1752.0	978.4	1534.1
Picloram & Clopyralid	0.28	2038.0	890.1	1350.4
Picloram & Clopyralid	0.42	1708.9	1672.1	1580.3
Picloram	0.14	1722.5	1066.9	2084.5
Picloram	0.28	1594.4	1448.8	1582.9
Picloram	0.42	1928.1	1660.7	1799.6
Control		565.9	477.4	711.7

[1] Burned plots

APPENDIX 3 (cont.)

Table 5a. Density (plants/m^2) of all species from the family Asteraceae

Herbicide	Rate (kg/ha)	Asteraceae[2]	Asteraceae[3]
Metsulfuron methyl[1]	0.035	1.4	5.1
Metsulfuron methyl	0.035	0.9	1.8
Metsulfuron methyl	0.07	0.7	1.2
Metsulfuron methyl	0.14	0.4	4.0
Clopyralid[1]	0.14	6.9	16.5
Clopyralid	0.14	3.8	15.9
Clopyralid	0.28	1.9	14.3
Clopyralid	0.42	0.9	3.3
Picloram & Clopyralid[1]	0.14	4.1	13.9
Picloram & Clopyralid	0.14	3.2	19.1
Picloram & Clopyralid	0.28	1.1	5.4
Picloram & Clopyralid	0.42	1.0	0.8
Picloram	0.14	1.8	13.0
Picloram	0.28	1.4	7.1
Picloram	0.42	2.0	1.6
Control		5.9	47.3

[1] Burned plots
[2] Lolo site
[3] Clearwater site

APPENDIX 3 (cont.)

Table 5b. Density (plants/m^2) of all species from the families Brassicaceae and Scrophulariaceae

Herbicide	Rate (kg/ha)	Brassicaceae[2]	Scrophulariaceae[3]
Metsulfuron methyl[1]	0.035	28.8	1.0
Metsulfuron methyl	0.035	16.5	1.1
Metsulfuron methyl	0.07	28.8	0.5
Metsulfuron methyl	0.14	9.1	0.1
Clopyralid[1]	0.14	26.3	2.8
Clopyralid	0.14	19.7	1.8
Clopyralid	0.28	12.9	1.2
Clopyralid	0.42	18.1	1.0
Picloram & Clopyralid[1]	0.14	15.1	3.6
Picloram & Clopyralid	0.14	13.3	3.1
Picloram & Clopyralid	0.28	11.6	1.2
Picloram & Clopyralid	0.42	12.1	1.2
Picloram	0.14	15.7	1.2
Picloram	0.28	6.1	1.3
Picloram	0.42	13.5	2.2
Control		11.4	1.3

[1] Burned plots
[2] Clearwater site
[3] Threemile site

APPENDIX 3 (cont.)

Table 6a. Forb density by species (plants/m^2)

Herbicide	Rate (kg/ha)	Nineleaf lomatium[3]	Western yarrow[2]	Rose pussytoes[3]	Arnica[3]
Metsulfuron methyl[1]	0.035	0.4	0.5	4.3	0.1
Metsulfuron methyl	0.035	0.1	0.1	1.1	0.1
Metsulfuron methyl	0.07	0.1	0.1	0.6	0.0
Metsulfuron methyl	0.14	0.0	0.0	2.6	0.3
Clopyralid[1]	0.14	6.0	5.9	10.8	4.5
Clopyralid	0.14	6.3	2.2	7.6	7.9
Clopyralid	0.28	2.8	1.0	10.4	3.4
Clopyralid	0.42	1.5	0.2	2.2	0.8
Picloram & Clopyralid[1]	0.14	6.0	0.9	10.4	2.7
Picloram & Clopyralid	0.14	3.3	1.6	10.1	8.0
Picloram & Clopyralid	0.28	1.6	0.2	0.7	4.4
Picloram & Clopyralid	0.42	0.4	0.1	0.6	0.2
Picloram	0.14	1.8	0.4	2.1	9.8
Picloram	0.28	0.7	0.5	2.2	4.5
Picloram	0.42	0.2	0.0	0.0	1.4
Control		12.2	7.1	22.8	18.4

[1] Burned plots
[2] Lolo site
[3] Clearwater site

APPENDIX 3 (cont.)

Table 6b. Forb density by species (plants/m²)

Herbicide	Rate (kg/ha)	Arrowleaf Balsamroot[2]	Oregon fleabane[2]	Field fluffweed[4]	Golden aster[2]
Metsulfuron methyl[1]	0.035	0.2	4.1	1.0	0.1
Metsulfuron methyl	0.035	0.3	0.1	0.4	0.6
Metsulfuron methyl	0.07	0.2	0.1	0.3	1.4
Metsulfuron methyl	0.14	0.2	0.0	0.4	1.6
Clopyralid[1]	0.14	0.2	5.3	3.6	0.4
Clopyralid	0.14	0.3	1.3	1.4	0.9
Clopyralid	0.28	0.3	0.5	0.9	0.3
Clopyralid	0.42	0.2	0.6	0.7	0.3
Picloram & Clopyralid[1]	0.14	0.2	6.9	1.5	0.0
Picloram & Clopyralid	0.14	0.3	2.5	0.6	0.7
Picloram & Clopyralid	0.28	0.4	0.9	0.1	0.1
Picloram & Clopyralid	0.42	0.1	1.3	0.4	0.2
Picloram	0.14	0.5	5.6	0.3	0.1
Picloram	0.28	0.3	2.0	0.2	0.1
Picloram	0.42	0.1	8.8	0.2	0.1
Control		0.7	3.3	0.2	0.3

[1] Burned plots
[2] Lolo site
[3] Clearwater site
[4] Threemile site

APPENDIX 3 (cont.)

Table 6c. Forb density by species (plants/m^2)

Herbicide	Rate (kg/ha)	Blanketflower[2]	Goldenrod[2]	Slender forget-me-not[3]
Metsulfuron methyl[1]	0.035	0.1	0.5	384.6
Metsulfuron methyl	0.035	0.0	0.7	285.8
Metsulfuron methyl	0.07	0.2	0.3	225.5
Metsulfuron methyl	0.14	0.0	0.0	346.6
Clopyralid[1]	0.14	2.9	8.5	410.6
Clopyralid	0.14	2.3	11.1	192.6
Clopyralid	0.28	3.1	1.4	241.3
Clopyralid	0.42	0.8	1.8	230.0
Picloram & Clopyralid[1]	0.14	2.9	3.8	327.3
Picloram & Clopyralid	0.14	2.1	4.1	85.7
Picloram & Clopyralid	0.28	1.7	1.3	246.6
Picloram & Clopyralid	0.42	1.7	0.9	112.5
Picloram	0.14	2.3	0.2	152.0
Picloram	0.28	1.4	1.2	35.7
Picloram	0.42	0.5	0.2	37.7
Control		1.1	1.4	228.1

[1] Burned plots
[2] Lolo site
[3] Clearwater site

APPENDIX 3 (cont.)

Table 6d. Forb density by species (plants/m²)

Herbicide	Rate (kg/ha)	Tumblemustard[3]	Sandwort[2]	Silky lupine[3]
Metsulfuron methyl[1]	0.035	0.0	0.4	6.3
Metsulfuron methyl	0.035	0.0	1.2	11.3
Metsulfuron methyl	0.07	0.0	0.4	6.2
Metsulfuron methyl	0.14	0.1	0.6	6.4
Clopyralid[1]	0.14	5.6	18.3	11.4
Clopyralid	0.14	8.4	18.1	6.7
Clopyralid	0.28	2.9	19.8	8.8
Clopyralid	0.42	4.6	18.3	6.3
Picloram & Clopyralid[1]	0.14	3.7	9.9	5.9
Picloram & Clopyralid	0.14	1.3	7.5	8.5
Picloram & Clopyralid	0.28	1.5	2.6	5.3
Picloram & Clopyralid	0.42	0.2	1.6	8.5
Picloram	0.14	0.4	4.0	6.3
Picloram	0.28	1.7	0.9	7.2
Picloram	0.42	0.3	0.2	4.3
Control		0.3	17.0	7.2

[1] Burned plots
[2] Lolo site
[3] Clearwater site

APPENDIX 3 (cont.)

Table 6e. Forb density by species (plants/m^2)

Herbicide	Rate (kg/ha)	Microsteris gracilis[3]	Microsteris gracilis[2]	Microsteris gracilis[4]
Metsulfuron methyl[1]	0.035	5.1	2.6	4.3
Metsulfuron methyl	0.035	8.8	3.8	6.5
Metsulfuron methyl	0.07	8.4	2.4	5.7
Metsulfuron methyl	0.14	4.1	1.5	1.3
Clopyralid[1]	0.14	5.8	2.2	2.3
Clopyralid	0.14	3.5	1.8	4.6
Clopyralid	0.28	5.0	2.5	3.2
Clopyralid	0.42	9.3	1.9	6.3
Picloram & Clopyralid[1]	0.14	2.1	0.8	1.4
Picloram & Clopyralid	0.14	3.3	0.4	1.7
Picloram & Clopyralid	0.28	1.3	0.0	1.0
Picloram & Clopyralid	0.42	3.5	0.3	1.1
Picloram	0.14	7.5	0.1	0.3
Picloram	0.28	1.0	0.0	0.0
Picloram	0.42	0.6	0.0	0.0
Control		46.4	4.9	8.3

[1] Burned plots
[2] Lolo site
[3] Clearwater site
[4] Threemile site

APPENDIX 3 (cont.)

Table 6f. Forb density by species (plants/m²)

Herbicide	Rate (kg/ha)	Douglas knotweed[3]	Sulfur erigeron[3]	Sheep sorrel[4]
Metsulfuron methyl[1]	0.035	16.2	1.9	0.0
Metsulfuron methyl	0.035	1.7	1.6	0.0
Metsulfuron methyl	0.07	2.5	1.2	0.0
Metsulfuron methyl	0.14	5.6	4.1	0.0
Clopyralid[1]	0.14	12.1	3.3	0.5
Clopyralid	0.14	1.3	3.9	0.5
Clopyralid	0.28	1.3	2.6	2.5
Clopyralid	0.42	3.1	1.4	1.8
Picloram & Clopyralid[1]	0.14	10.9	0.9	3.0
Picloram & Clopyralid	0.14	3.8	3.6	0.5
Picloram & Clopyralid	0.28	1.3	1.8	0.1
Picloram & Clopyralid	0.42	3.3	1.5	0.6
Picloram	0.14	2.5	0.5	0.2
Picloram	0.28	4.5	0.4	0.1
Picloram	0.42	6.5	0.0	0.0
Control		4.2	3.2	0.8

[1] Burned plots
[3] Clearwater site
[4] Threemile site

APPENDIX 3 (cont.)

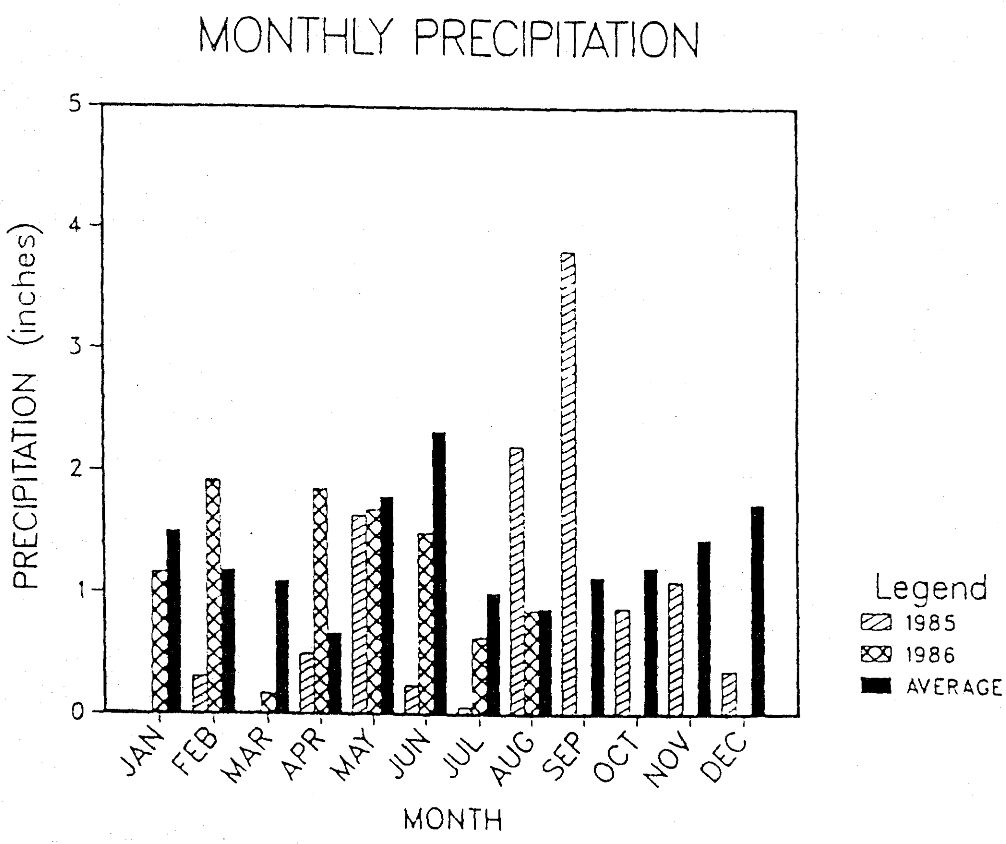
Table 6g. Forb density by species (plants/m^2)

Herbicide	Rate (kg/ha)	Northwest cinquefoil[2]	Small-flowered blue-eyed mary[3]
Metsulfuron methyl[1]	0.035	1.1	34.6
Metsulfuron methyl	0.035	1.3	8.3
Metsulfuron methyl	0.07	1.9	13.3
Metsulfuron methyl	0.14	0.8	5.8
Clopyralid[1]	0.14	8.6	30.5
Clopyralid	0.14	9.0	29.8
Clopyralid	0.28	6.2	28.4
Clopyralid	0.42	6.4	31.4
Picloram & Clopyralid[1]	0.14	2.8	51.1
Picloram & Clopyralid	0.14	0.5	14.3
Picloram & Clopyralid	0.28	0.3	35.2
Picloram & Clopyralid	0.42	0.3	30.5
Picloram	0.14	0.0	26.8
Picloram	0.28	0.0	26.5
Picloram	0.42	0.0	63.9
Control		8.4	30.7

[1] Burned plots
[2] Lolo site
[3] Clearwater site

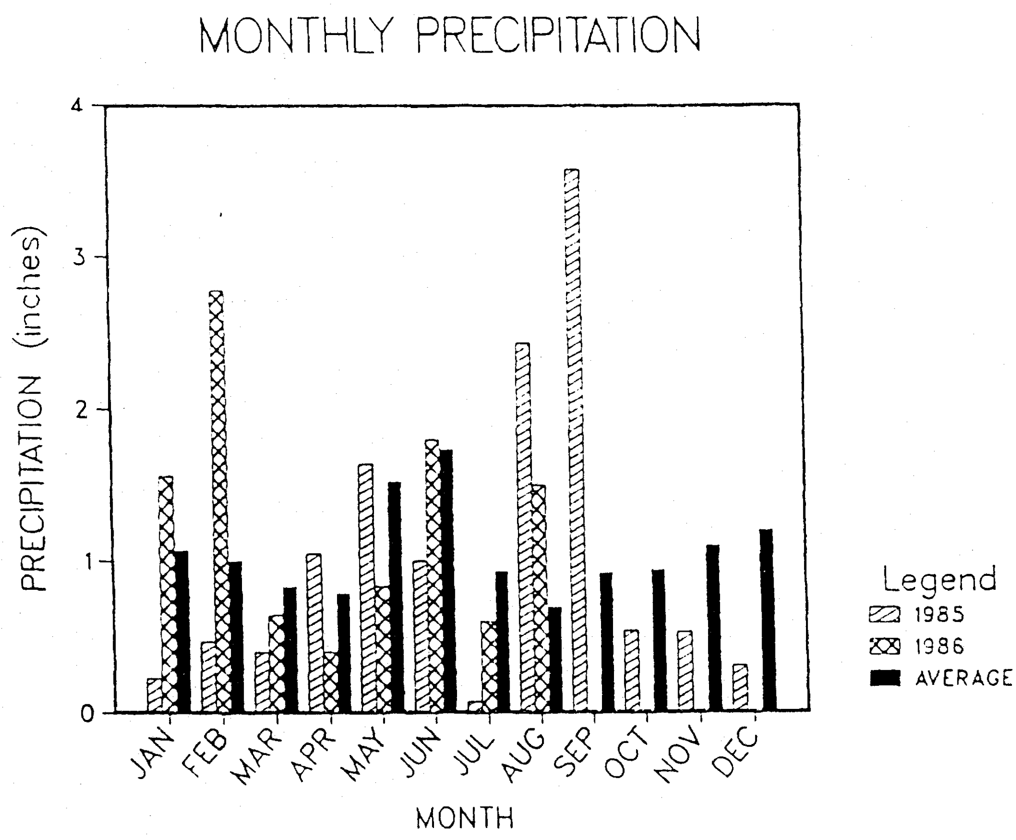
APPENDIX 4

Approximate monthly precipitation received at Clearwater during 1985 and 1986 compared to average monthly precipitation.



APPENDIX 5

Approximate monthly precipitation received at Lolo and Threemile during 1985 and 1986 compared to average monthly precipitation.



APPENDIX 6

Disturbance Key. This key was used to translate disturbance classes into a numerical disturbance variable. In this case, Reproductive Effort was assigned three times the importance of Amount of Soil Exposed (See note below). Total points from Amount of Soil Exposed, On-Site Seed Bank, and On-Site Reproductive Capacity are summed for total disturbance score.

	Score
I. Amount of Soil Exposed	
A. Small area	
1. One time	4.17
2. Over several years	8.33
B. Moderate amount of area	
1. One time	12.50
2. Over several years	16.66
C. Entire area exposed	
1. One time	20.83
2. Over several years	25.00
II. Total Reproductive Effort	
A. On-site seed bank	
1. Slightly reduced	
a. One time	6.25
b. Over several years	12.50
2. Moderately reduced	
a. One time	18.75
b. Over several years	25.00
3. Demolished	
a. One time	31.25
b. Over several years	37.50
B. On-site reproductive effort	
1. Slightly reduced	
a. One time	6.25
b. Over several years	12.50
2. Moderately reduced	
a. One time	18.75
b. Over several years	25.00
3. Demolished	
a. One time	31.25
b. Over several years	37.50

Note: Other disturbance keys that were used initially assigned 1) 75 points to Amount of Soil Exposed + 25 points to Total Reproductive effort, 2) 50 points to Amount of Soil Exposed + 50 points to Total Reproductive Effort, and 3) 50 points to Amount of Soil Exposed + (50 points to Total Reproductive Effort)[a]. The variable produced by the disturbance key displayed above was used for statistical analyses because in the Factor Analysis Model, it explained the greatest amount of variation in plant distance. The disturbance variable that explained the least amount of variation (68%) was Number 1 listed above.

APPENDIX 7
List of Average Plant Distances in Each Habitat Type Both off Roads and on Roads

Habitat Type	Off Roads Avg. Plant Dist. (m)	n	On Roads Avg. Plant Dist. (m)	n
Dry Group:				
Purshia tridentata/Agropyron spicatum	2.095	6	0.100	1
Artemisia tridentata/Agropyron spicatum	0.602	3	0.100	1
Festuca idahoensis/Agropyron spicatum	1.253	5	0.145	4
Agropyron spicatum/Poa sandbergii	2.394	5	0.453	3
Festuca scabrella/Agropyron spicatum	5.008	5	4.475	3
Artemisia tridentata/Festuca scabrella	6.685	2	0.130	1
Festuca scabrella/Festuca idahoensis	3.298	5	0.305	4
Ponderosa Pine Group:				
Pinus ponderosa/Agropyron spicatum	2.446	11	0.587	7
Pinus ponderosa/Purshia tridentata	3.505	1	0.100	1
Pinus ponderosa/Festuca idahoensis	1.898	10	0.903	7
Douglas-fir Group:				
Pseudotsuga menziesii/Arctostaphylos uva-ursi	6.315	1	-	-
Pseudotsuga menziesii/Agropyron spicatum	3.864	7	1.217	8
Pseudotsuga menziesii/Festuca scabrella	3.920	1	0.100	1
Pseudotsuga menziesii/Symphoricarpos albus	2.479	48	0.353	49
Pseudotsuga menziesii/Spirea betufolia	5.863	2	1.833	2
Pseudotsuga menziesii/Calamagrostis rubescens	3.579	21	0.436	19
Pseudotsuga menziesii/Vaccinium globulare	4.072	17	0.369	17
Pseudotsuga menziesii/Physocarpos malvaceus	3.892	33	0.351	31
Pseudotsuga menziesii/Vaccinium caespitosum	2.391	8	0.256	8
Pseudotsuga menziesii/Linnaea borealis	9.835	3	1.333	3
Wet Group:				
Pinus contorta/Vaccinium caespitosum	9.300	2	-	-
Picea/Vaccinium caespitosum	3.623	2	0.108	2
Picea/Linnaea borealis	8.353	3	3.868	3
Picea/Physocarpos malvaceus	1.635	1	0.140	1
Abies grandis/Xerophyllum tenax	6.535	1	0.155	1
Abies grandis/Linnaea borealis	3.217	3	0.108	3
Abies grandis/Clintonia uniflora	7.408	4	1.565	4
Abies lasiocarpa/Xerophyllum tenax	5.019	4	3.919	4
Abies lasiocarpa/Linnaea borealis	0.145	1	0.120	1
Abies lasiocarpa/Clintonia uniflora	7.708	2	0.585	2
Thuja plicata/Clintonia uniflora	5.951	6	3.688	6
Tsuga heterophylla/Clintonia uniflora	8.235	1	0.100	1

APPENDIX 8.
Growth chamber conditions.

Time	Temperature (°C)	Humidity (%)	Light
00:00	14	90	0
01:00	13	90	0
02:00	12	90	0
03:00	11	90	0
04:00	10	95	0
05:00	8	95	0
06:00	9	90	1:1
07:00	10	90	2:2
08:00	12	85	3:3
09:00	14	85	4:4
10:00	16	80	4:4
11:00	18	80	4:4
12:00	19	75	4:4
13:00	20	75	4:4
14:00	21	70	4:4
15:00	22	70	4:4
16:00	23	65	4:4
17:00	24	65	4:4
18:00	25	70	4:4
19:00	23	75	3:3
20:00	22	80	2:2
21:00	20	85	1:1
22:00	18	90	0:0
23:00	16	90	0:0